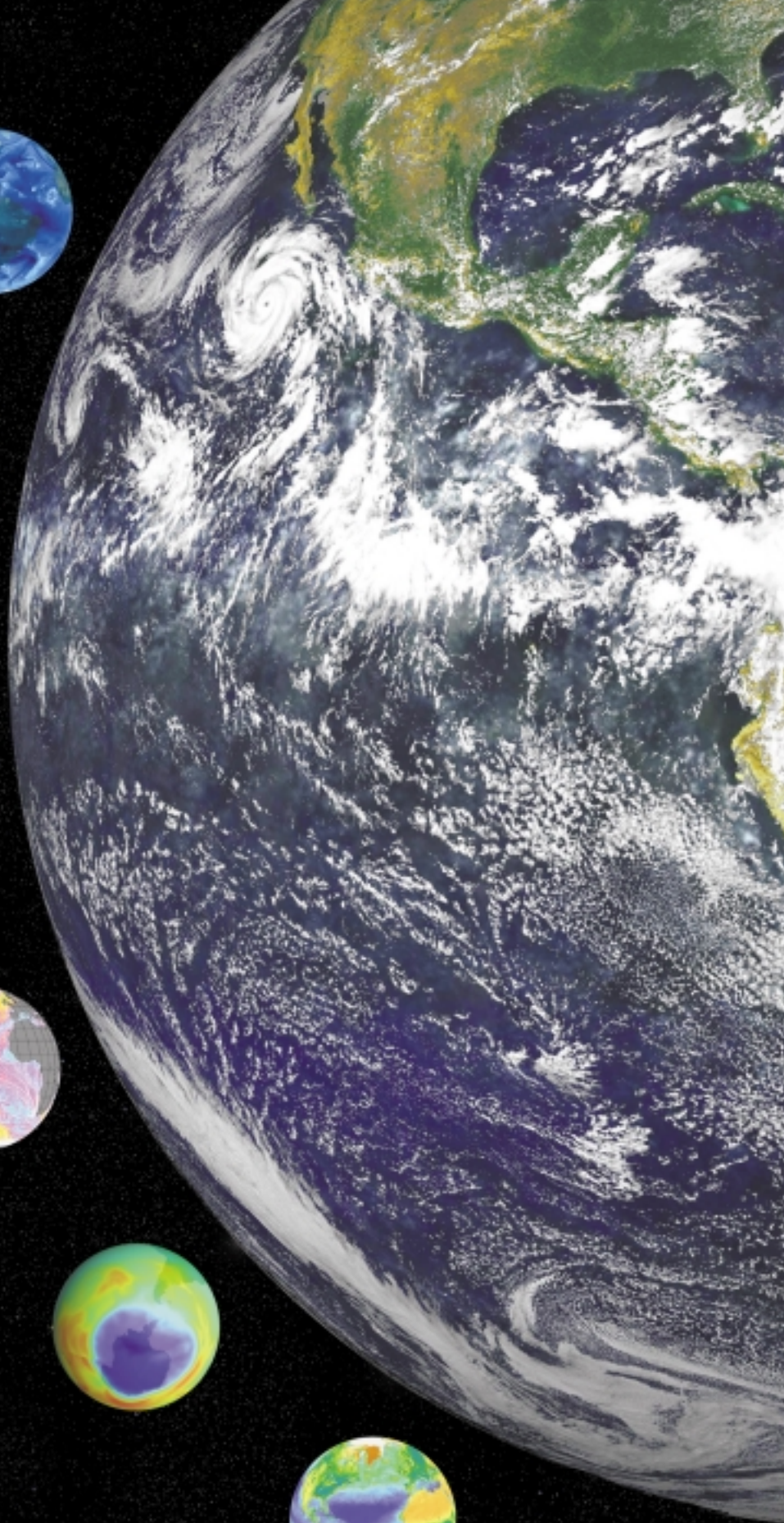
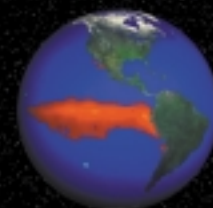
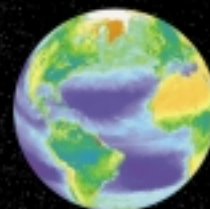
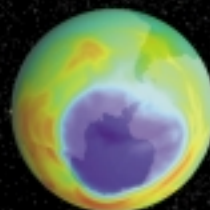
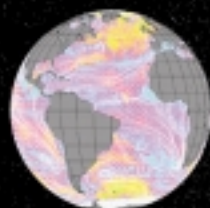
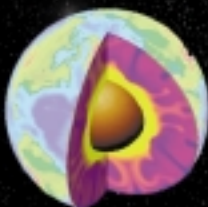
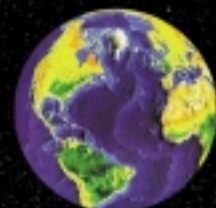
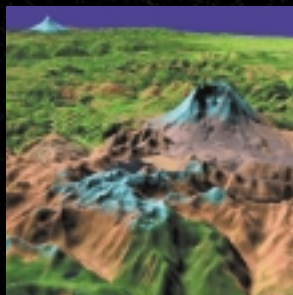
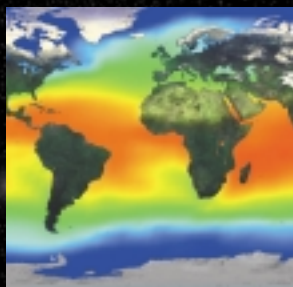


# Exploring Our Home Planet

## Earth Science Enterprise

### Strategic Plan



# **How is the Earth changing and what are the consequences for life on Earth?**

How is the global Earth system changing?

What are the primary causes of change in the Earth system?

How does the Earth system respond to natural and human-induced changes?

What are the consequences of change in the Earth system for human civilization?

How well can we predict future changes in the Earth system?



## **The Earth Science Enterprise Mission:**

*Develop a scientific understanding of the Earth system and its response to natural and human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations.*

To the Reader:

NASA's Earth Science Enterprise is dedicated to understanding the total Earth system and the effects of natural and human-induced changes on the global environment. The vantage point of space provides information about Earth's land, atmosphere, ice, oceans, and biota that is obtainable in no other way. Programs of the Enterprise study the interactions among these components to advance the new discipline of Earth System Science, with a near-term emphasis on global climate change. Our research results contribute to the development of sound environmental policy and economic investment decisions.

NASAs' Earth Science Enterprise develops innovative technologies and applications of remote sensing for solving practical societal problems in food and fiber production, natural hazard mitigation, regional planning, water resources, and national resource management in partnership with other Federal agencies, with industry, and with state and local governments. Earth Science discoveries are shared with the public to enhance science, mathematics, and technology education and increase the scientific and technological literacy of all Americans. Earth Science combines the excitement of scientific discovery with the reward of practical contribution to the sustainability of planet Earth.

Earth Science is science in the national interest. NASA is pleased to play a leadership role in exploring our home planet. This Earth Science Enterprise Strategic Plan describes our approach to science and applications research in this great endeavor. Three subordinate documents, the *Earth Science Enterprise Research Strategy*, the *Technology Strategy*, and the *Applications Strategy*, provide more detail in these important areas. I invite you to learn more about NASA's Earth Science Enterprise through our Web site at <http://www.earth.nasa.gov>.

A handwritten signature in dark ink, appearing to read 'Ghassem R. Asrar', with a stylized, flowing script.

Ghassem R. Asrar

Associate Administrator for Earth Science

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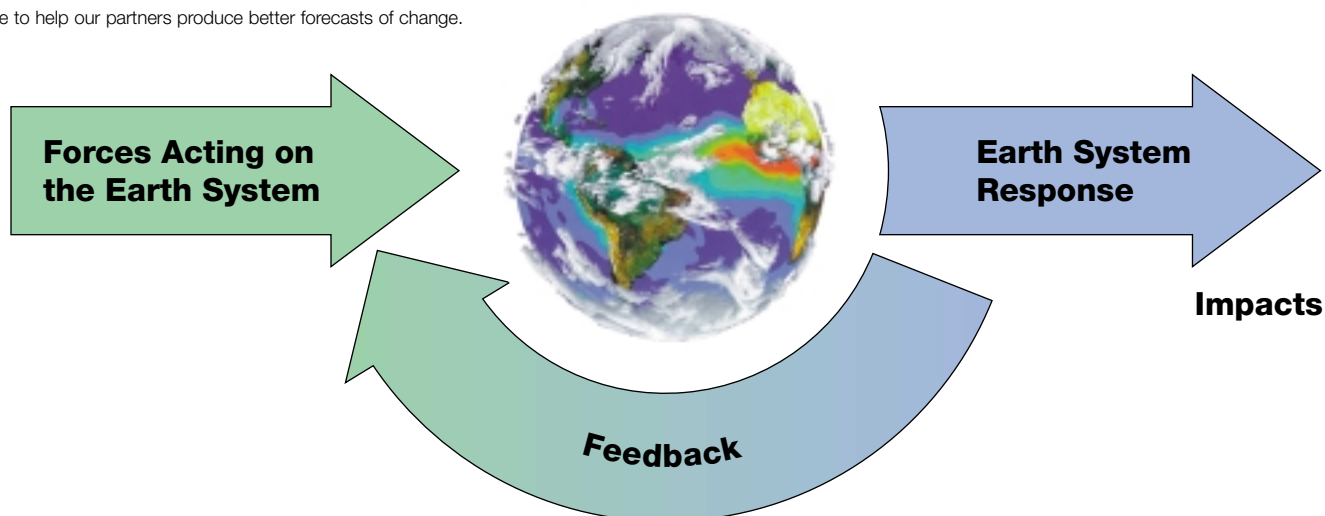
# Introduction: Understanding the Earth System

NASA's Earth observing satellites and related research have led scientists to view the Earth as a system—as a dynamic set of interactions among the land surface, atmosphere, oceans and ice caps, and the Earth's interior. This profound realization gave rise to the birth of the new interdisciplinary field of Earth System Science. This way of studying the Earth is critical to understanding how global climate responds to the forces and feedbacks acting on it.

For much of human history, humankind labored to adapt itself to patterns and variability of the Earth system—most notably in climate. Over the past several centuries, the balance shifted toward humankind, adapting natural world for human purposes, most notably in agriculture, housing, transportation, and energy generation. Most recently, the circle has been closed—human activity is now powerful enough to begin to affect the planet. While impacts of human activities have long been apparent at the local level, we are now seeing global-scale impacts, first in stratospheric ozone depletion and now perhaps in changing climate. And, as if to remind us of our limits, the Earth continues to offer disruptions of its own in the form of earthquakes, volcanic eruptions, and severe weather.

Researchers have constructed computer models to simulate the Earth system, and to explore the possible outcomes of potential changes they introduce in the models. This way of looking at the Earth as a system is a powerful means of understanding changes we see around us. That has two implications for Earth Science. First, we need to characterize (that is, identify and measure) the forces acting on the Earth system and its responses. Second, we have to peer inside the system to understand the source of internal variability: the complex interplay among components that comprise the system. Earth system changes are global phenomena. Yet the system comprises many microscale processes, and the most significant manifestations are regional. Thus, studying such changes requires a global view at regionally-discerning resolutions. This is where NASA comes in, bringing the unique capability to study planet Earth from the vantage point of space. By combining observations, research, and modeling, we create a capability to predict Earth system change to help our partners produce better forecasts of change.

We know that natural and human-induced changes are acting on the Earth system. Natural forces include variation in the Sun's energy output, and volcanic eruptions which spew dust and gases into the atmosphere and scatter incoming sunlight. Human forces include deforestation, carbon emission from the burning of fossil fuels, methane and soil dust production from agriculture, and ozone depletion by various industrial chemicals. Internal climate factors such as atmospheric water vapor and clouds also introduce feedbacks which serve to either dampen or enhance the strength of climate forcing. We also know the climate system exhibits considerable variability in time and space, i.e., both short and long term changes and regionally-specific impacts.



# Applying Earth Science to Practical Problems

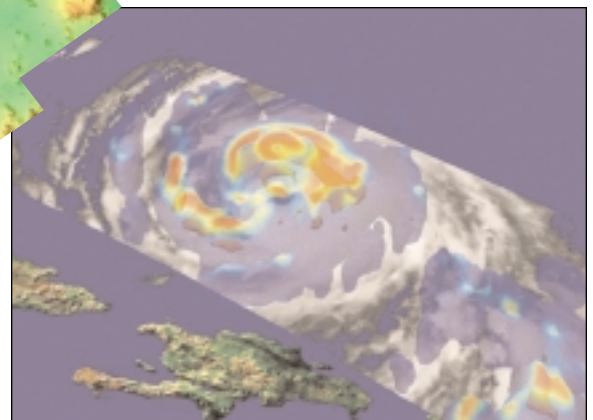
Knowledge gained about the Earth System has many practical applications, one of which is improved preparedness for Natural hazards. Large natural disasters were three times more frequent in the 1990's compared to the 1960's, and disaster costs were nine times as great. Natural hazard risks and losses are increasing with concentration of people and property assets in economically valuable but naturally vulnerable areas. In the United States alone, the 1990's saw some of the most expensive natural disasters in our history, including the Missouri River floods ('92), Hurricane Andrew ('92), and the Northridge Earthquake ('94). The linkage of natural disasters to climate and other Earth system changes is an active area of research.

If we understand the processes leading to earthquakes, hurricanes, volcanic eruptions, floods, and other hazards, we can help other Federal and State agencies mitigate the loss of life and property through improved planning, improved response, and more efficient post-event recovery. Space-based technology has the potential to significantly contribute to efforts to reduce the losses due to inevitable natural disasters. ESE research is focused on modeling the relevant Earth system processes to achieve reliable prediction capability. ESE coordinates this research with NOAA, the Federal agency with responsibility for operational weather and climate forecasting, so they can factor these models into their forecasts. We partner with USGS to monitor land surface motion in the Los Angeles Basin and characterize land surface worldwide, and we partner with FEMA to improve their flood plain mapping and disaster preparedness. The spread of certain infectious diseases, such as malaria, dengue fever, and Rift Valley fever, is a function of regional, seasonal climate conditions. NASA and the National Institutes of Health are employing remote sensing data to predict and hopefully head off instances of disease outbreaks.

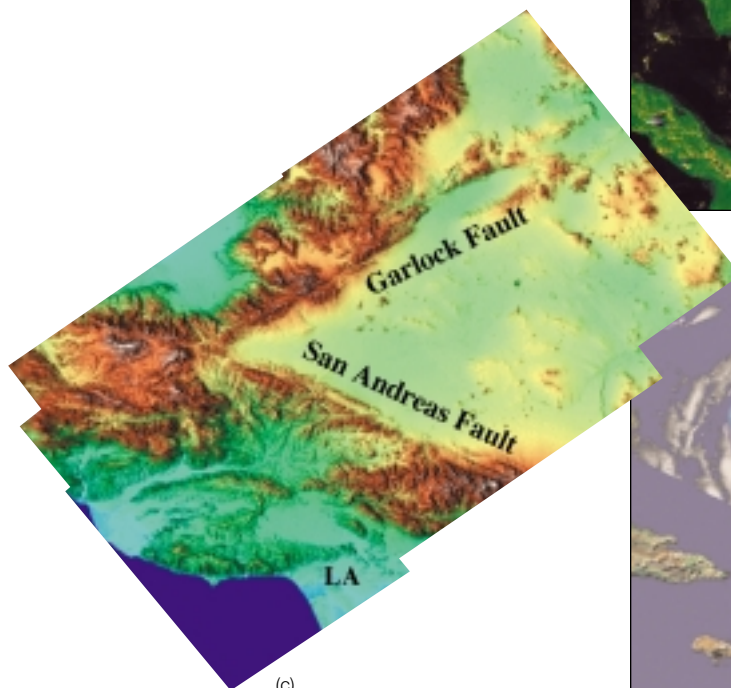
Computer-generated 3-D visualization based on satellite observation helps put large scale storms in perspective. Using wind speed and direction data from the QuikSCAT satellite (a) and precipitation measurements from the TRMM satellite (b), NASA-sponsored researchers are demonstrating new capabilities to improve storm track and strength prediction for NOAA. NASA and NIMA partnered on the Shuttle Radar Topography Mission to produce 3-D maps of most of the Earth's surface (c). These maps will be used in applications such as flood plain mapping and aircraft ground collision avoidance as well as for research on how the Earth's surface reflects changes in Earth's interior.



(a)

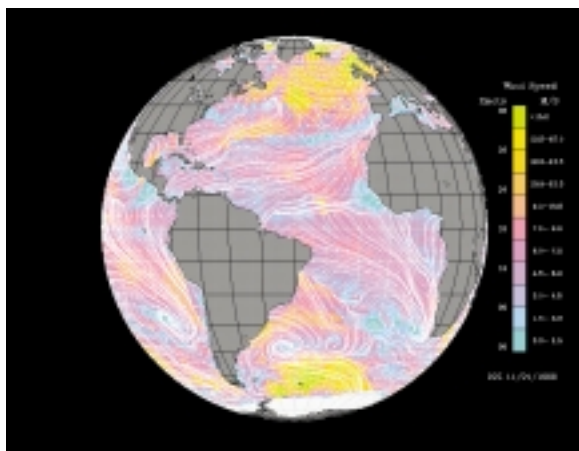


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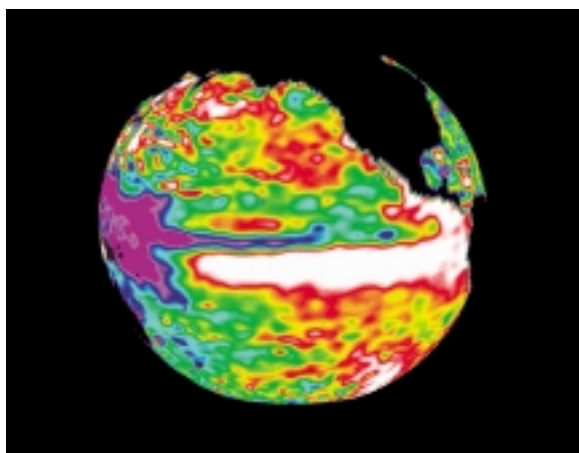


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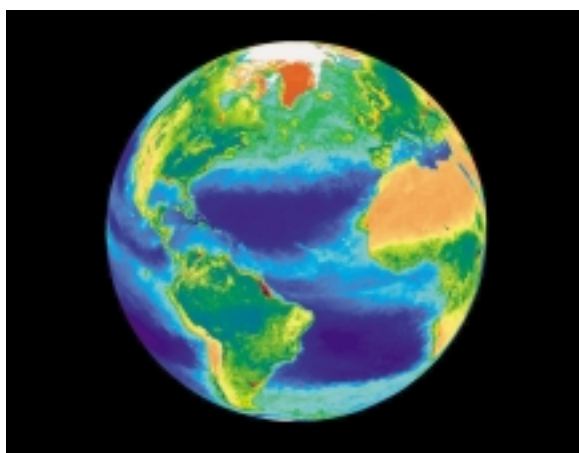
# NASA's View of the Earth from Space . . .



Wind speed and direction at the ocean surface



El Niño as indicated by sea surface height



The biosphere—land and ocean chlorophyll

The history of national and international concern with global change issues parallels NASA's history.

The Space Age began during the first International Geophysical Year in 1957. From the beginning, science from space focused on Earth as well as other planets and stars.

**In the early 1960's**, the first weather satellites launched by NASA made it obvious that the view from space is essential to the study of global phenomena. Weather satellites made possible today's 3- to 5-day weather forecasts. National awareness of environmental concerns was stimulated in part by Apollo's views of Earth as a lone outpost of life in the vast blackness of space.

**In the early 1970's**, NASA began to experiment with technologies for remote sensing of land surface features and vegetation, and Landsat became the world's first civilian land imaging satellite. Landsat is now the basic tool for scientific research on regional to global land cover change, helping to resolve such questions as the rate of deforestation in the Amazon and Southeast Asia, and enabling crop yield prediction in the US midwest by observing the "greening up" over the growing season.

**In the 1980's**, the satellite-based Earth Radiation Budget Experiment and others enabled the study of solar radiation and Earth's absorption and reflection of it to construct the first model of the Earth's energy budget.

**In the 1970's and '80's**, NASA's Total Ozone Mapping Spectrometer began global monitoring of the annual fluctuations in ozone concentration and distribution, including the growth of the now-famous Antarctic "ozone hole," leading to the adoption by virtually all the world's nations of the Montreal Protocol on Substances Depleting the Ozone Layer. In the 1990's, NASA's Upper Atmosphere Research Satellite confirmed the source of ozone-destroying compounds to be industrially-produced chemicals.

**In the early 1990's**, we embarked on a new era in Earth remote sensing with the NASA/French TOPEX/Poseidon radar altimeter, which provides the first global maps of ocean circulation, and allows nations to monitor the progress of El Niño/La Niña formation and dissipation. This has set the stage for prediction of Earth's climate 12 to 18 months in advance.

**In the late 1990's**, NASA and private industry teamed up to deploy an ocean "color" (phytoplankton concentration) measuring instrument called SeaWiFS to understand the role of the oceans in removing CO<sub>2</sub> from the atmosphere. NASA and Japan launched the Tropical Rainfall Measuring Mission (TRMM) to produce the first measurements of rainfall over the global tropics and its contribution to global distribution of fresh water.

These and other exploratory missions led to the conclusion that the keys to understanding climate lay in the interactions among the land surface, atmosphere, oceans and ice caps, and the Earth's interior.

**In 2000, we are entering a new era of Earth observation from space.**

# ... Enables Study of the Earth System

## EARTH SCIENCE ENTERPRISE MISSION, GOALS, AND OBJECTIVES

Develop a scientific understanding of the Earth system and its response to natural and human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations.

### 1. Science . . .

Observe, understand, and model the Earth system to learn how it is changing, and the consequences for life on Earth.

- Discern and describe how the Earth is changing (Variability)
- Identify and measure the primary causes of change in the Earth system (Forcing)
- Determine how the Earth system responds to natural and human-induced changes (Response)
- Identify the consequences of change in the Earth system for human civilization (Consequence)
- Enable the prediction of future changes in the Earth system (Prediction)

### 2. Applications . . .

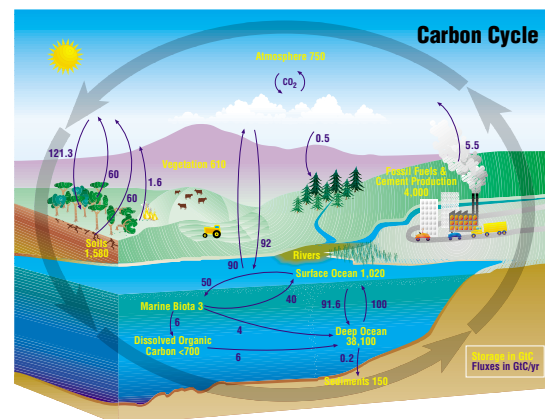
Expand and accelerate the realization of economic and societal benefits from Earth science, information, and technology.

- Demonstrate scientific and technical capabilities to enable the development of practical tools for public and private sector decisionmakers
- Stimulate public interest in and understanding of Earth system science and encourage young scholars to consider careers in science and technology

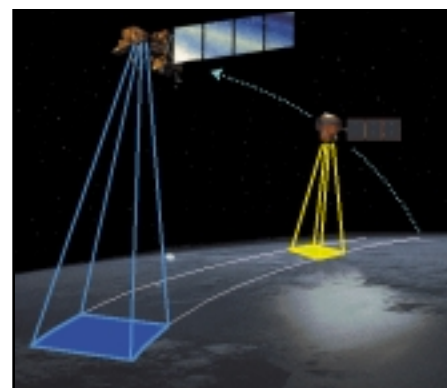
### 3. Technology . . .

Develop and adopt advanced technologies to enable mission success and serve national priorities.

- Develop advanced technologies to reduce the cost and expand the capability for scientific Earth observation
- Develop advanced information technologies for processing, archiving, accessing, visualizing, and communicating Earth science data
- Partner with other agencies to develop and implement better methods for using remotely sensed observations in Earth system monitoring and prediction

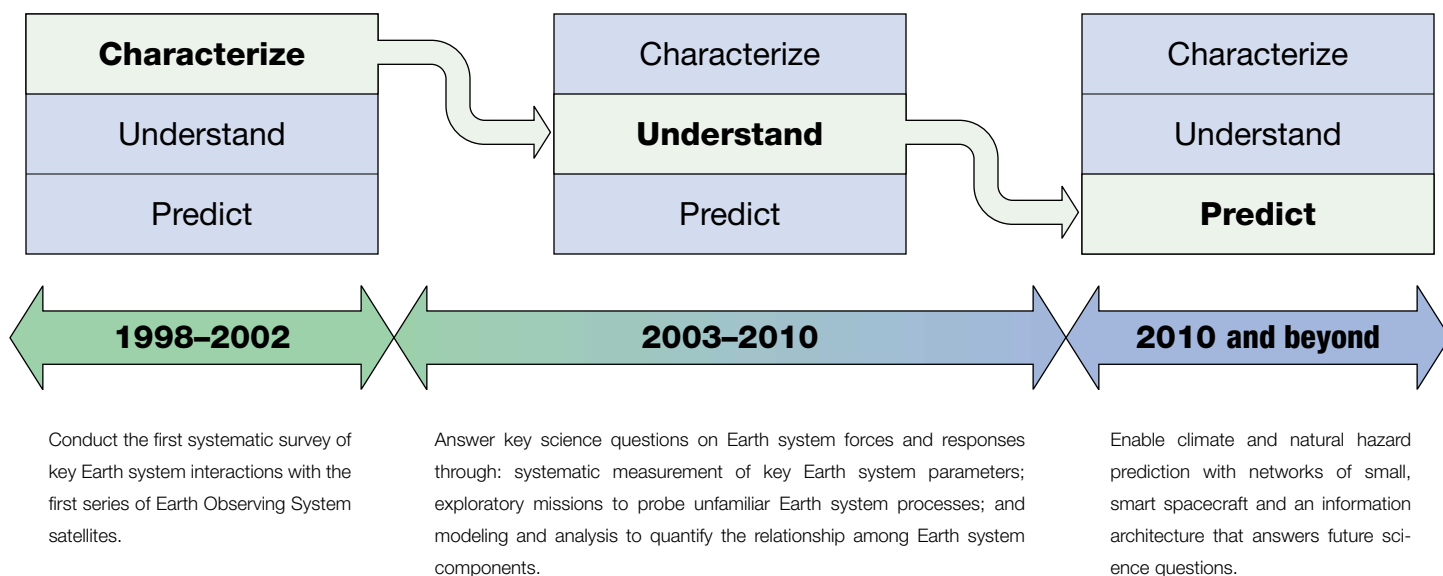


Pamlico River, NC, before and after Hurricane Floyd

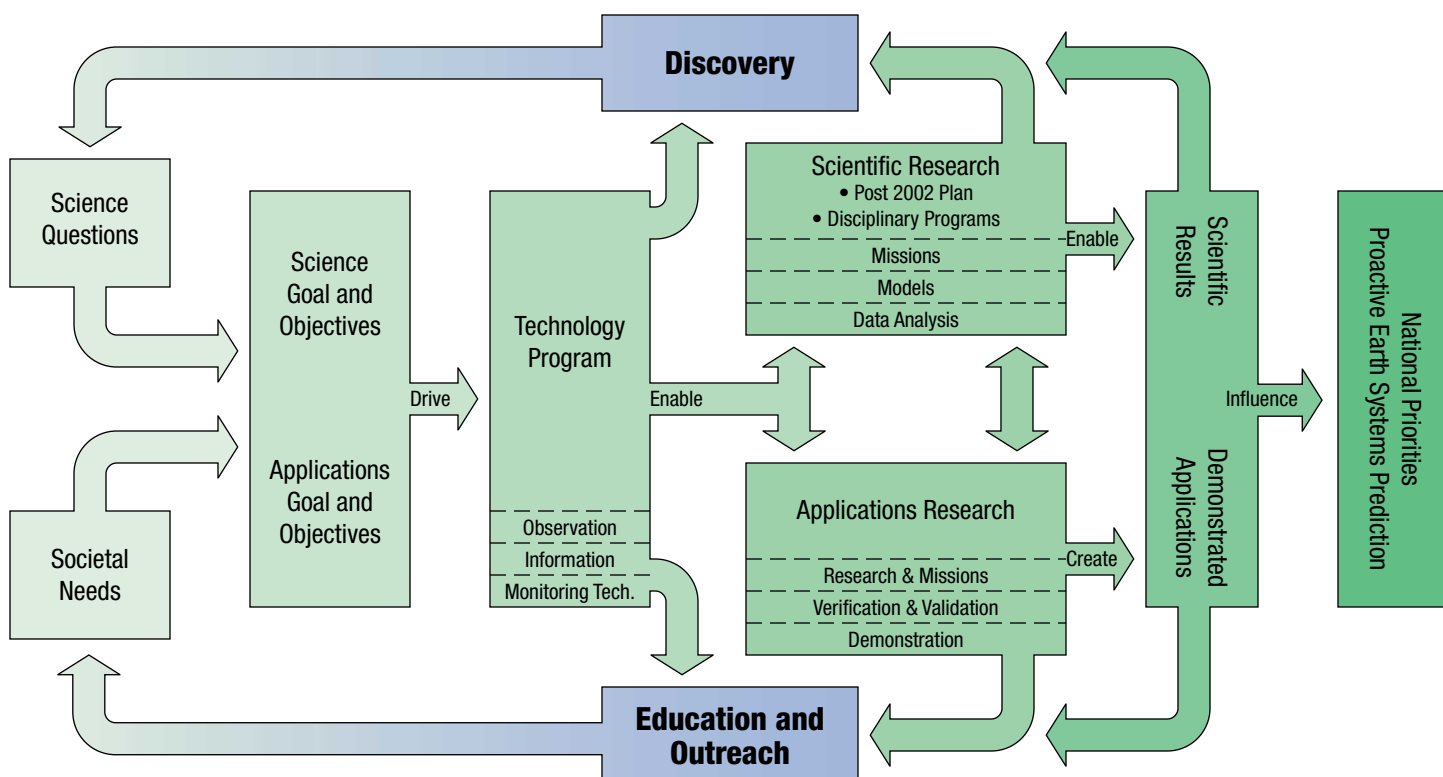


Advanced Land Imager EO-1 flying in formation with Landsat 7

# Framework for Strategic Planning



## From Science Questions to Predictive Capability



# NASA Earth Science Enterprise Roadmap

## Objectives

### Science

- Understand Earth system variability
- Identify and measure primary causes of change
- Determine how the Earth system responds
- Identify the consequences for civilization
- Predict future Earth system changes

### Applications and Education

- Demonstrate scientific and technical capabilities for practical tools for public and private sector decisions
- Stimulate public understanding of Earth science and encourage careers in science and technology

### Technology

- Develop advanced technologies for Earth observation
- Develop advanced information technologies for Earth science data
- Partner with others for Earth system monitoring and prediction

## Through 2002 Characterize the Earth System

- Establish a benchmark for global rainfall
- Estimate uptake of atmospheric CO<sub>2</sub> from global measurements of the terrestrial biosphere
- Provide precise global measurements of atmospheric temperature and humidity
- Make global measurements of cloud properties to determine Earth's response to solar radiation
- Measure global ocean winds and topography to improve accuracy and length of weather prediction and drive models of ocean impacts on climate change
- Produce 3-D maps of the entire inhabited surface of the Earth

## 2003-2010 Understand the Earth System

- Achieve a quantitative understanding of the global fresh water cycle
- Quantify with a "high" or "moderate" degree of confidence the principal Earth system forcing and response factors
- Quantify the variation and trends in terrestrial and marine ecosystems; estimate global carbon stocks in forests and oceans
- Assess impacts of climate change on global ecosystems using interactive ecosystem-climate models
- Assimilate ocean surface winds, ocean topography, sea surface temperature, and precipitation into climate and weather forecasting models

## 2010-2025 and Beyond Predict Changes in the Earth System

- Conduct research to demonstrate capability for:  
*10-year climate forecasts*  
*12-month rain rate*  
*7-day forecast of pollution alerts*  
*60-day volcanic eruption prediction*  
*15- to 20-month El Niño forecasts*  
*5-day hurricane track forecast*  
*1- to 5-year earthquake forecast (experimental)*
- Assess sea-level rise and effects
- Predict regional impacts of decadal climate change

- Demonstrate applications of geospatial data to agriculture, forestry, urban, and transportation planning, etc.
- Expand use of commercial systems in collecting Earth system science data
- Collaborate with educators to develop new curricula support materials using Earth science data and discoveries

- Conduct research to enable 7- to 10-day weather and seasonal precipitation prediction capability; enable broad use of data in precision agriculture
- Enable an effective mix of private, government, and international data sources and users
- Incorporate Earth System Science into education curricula at the K-14 and university levels

- Conduct research to enable 10- to 14-day weather and annual precipitation prediction capability
- Enable wide spread commercial supply and use of global environmental data; integration of environmental information and economic decisionmaking
- Sponsor education and training programs to produce the next generation of Earth System Scientists

- Implement satellite formation flying to improve science return; New Millennium Program to space-validate revolutionary technologies
- Explore new instrument concepts for next decade science missions
- Employ high-end super computers to address Earth system modeling challenges
- Collaborate with operational agencies in mission planning, development, and utilization

- Develop and implement autonomous satellite control
- Demonstrate a new generation of small, highly capable active, passive, and in situ instruments
- Employ distributed computing and data mining techniques for Earth system modeling
- Transition advanced instruments for systematic measurements to operational systems
- Develop high data rate communications and on-board data processing and storage

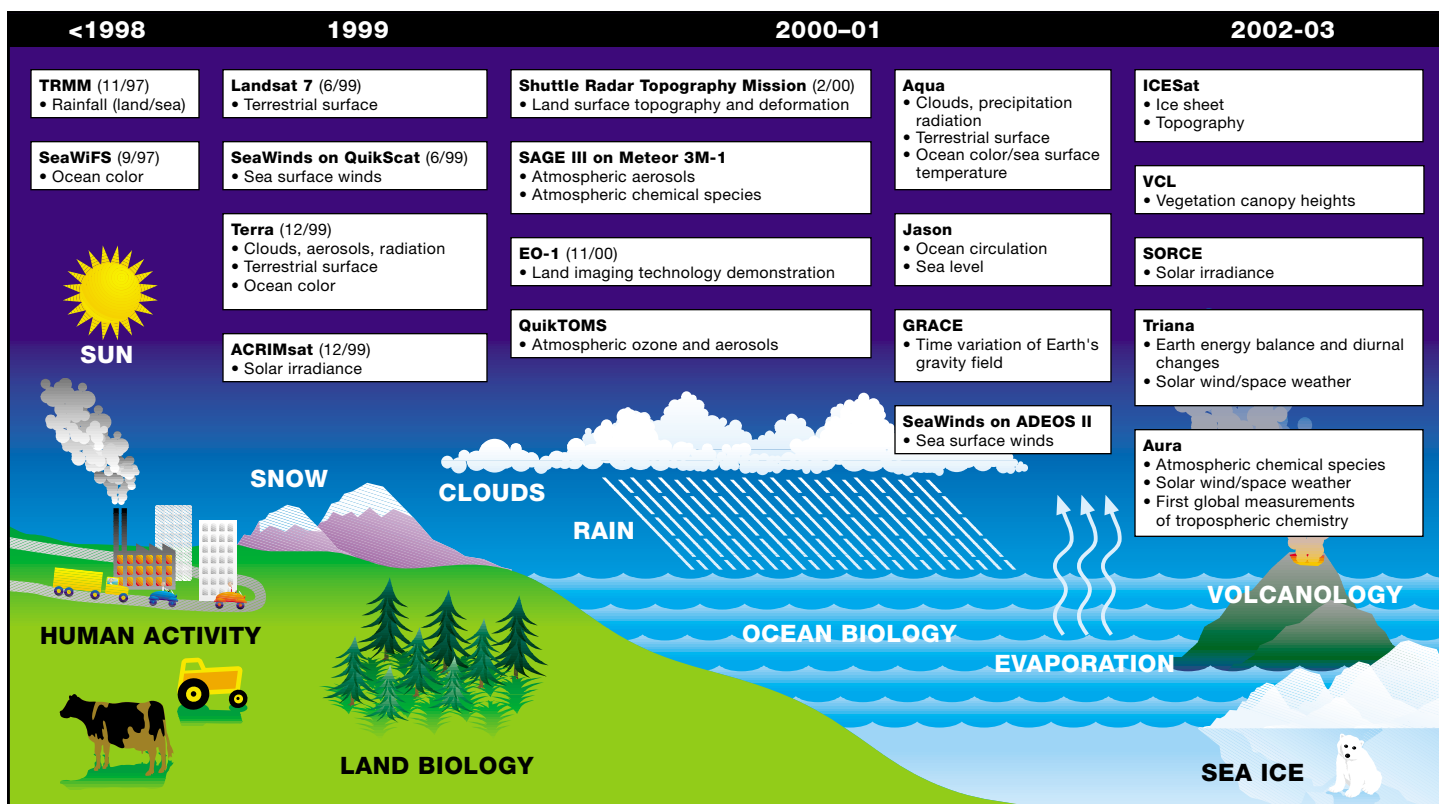
- Deploy cooperative satellite constellations and intelligent sensor webs
- Design instruments for new scientific challenges; deploy advanced instruments to migrate selected observations from LEO and GEO to L1 and L2 sentinels
- Develop a collaborative synthetic environment to facilitate understanding and enable remote use of models and results
- Collaborate in an international global observing and information system; improve operational systems with new technology

# The Current Program (Through 2002): Characterizing the Earth System

## SCIENCE AND APPLICATIONS ACCOMPLISHMENTS:

- Quantified the flux of radiation from the Sun and the Earth's planetary energy budget
- Created a 26-year data record of global land cover, to quantify changes such as the rate of deforestation in the Amazon and Southeast Asian rainforests
- Discovered the causes of ozone depletion and formation, and established that industrially-produced, chlorine-containing compounds are responsible for observed increases in ozone depletion
- Generated the first maps of global ocean circulation from satellite data, and enabled the world to watch the formation and dissipation of El Niño and La Niña phenomena
- Determined thinning and thickening rates for the Greenland ice sheet, and produced the first precise radar map of Antarctica
- Mapped earthquake faults and ground motions prior to volcanic eruptions using interferometric radars and GPS arrays
- Discovered that high concentrations of atmospheric pollutants can inhibit rainfall in areas downwind of their source(s)
- Discovered a significant decrease in high Northern latitude sea ice thickness over the past few decades

**NASA'S CURRENT EARTH SCIENCE MISSIONS  
ARE CHARACTERIZING THE MAJOR  
INTERACTIONS IN THE EARTH SYSTEM**



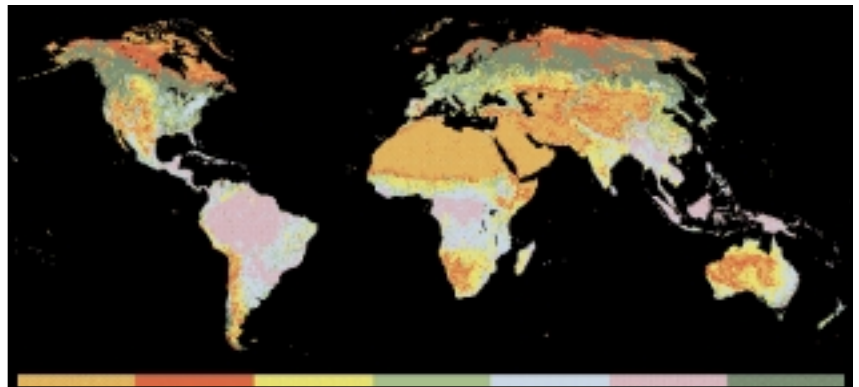
# The Current Program (continued)

## ANTICIPATED ACCOMPLISHMENTS:

- Collect nearly daily global measurements of the terrestrial and marine biosphere from which estimates of uptake of atmospheric carbon dioxide can be made
- Establish a benchmark for global and regional rainfall measurements which determines availability of fresh water resources
- Provide precise global measurements of atmospheric temperature and humidity from satellites to improve accuracy and length of weather forecasts, and continue ocean wind and topography measurements to improve accuracy and length of weather prediction and drive models of the ocean's impact on climate
- Make global measurements of cloud properties (extent, height, reflectivity, microphysics, etc.) to determine their impact on the Earth's response to incoming solar radiation and Earth's climate
- Make global measurements of aerosols and ozone as indicators of air quality in the troposphere—the portion of the atmosphere in which we live and breathe
- Produce a digital topographic map for the entire Earth surface between 60°N and 56°S, useful for a wide variety of research and applications in natural hazards, hydrology, geomorphology, etc.; provide additional coverage with digital elevation models generated from the Terra satellite
- Understand processes contributing to formation and occurrence of earthquakes and volcanic systems

## IMPLEMENTATION PRIORITIES:

- Continue the development of the first series of EOS and selected Earth Probes missions
- Deliver a functioning data and information system to support the processing, archival, and distribution of data and information resulting from these missions
- Implement scheduled aircraft and field campaigns, e.g., detailed aircraft study of Pacific tropospheric chemistry, the ecology of the Amazon, and biomass burning in southern Africa
- Continue collection and analysis of data from existing NASA satellites, e.g., data on rainfall rates in the global tropics and phytoplankton concentrations in the oceans
- Establish joint applications demonstration projects with other Federal, State and, local agencies (e.g., FEMA flood plain mapping, USDA precision agriculture)
- Conduct research on key Earth science questions in collaboration with other Agencies, e.g., measure changing crustal strain field with USGS and NSF—“EarthScope”
- Support the development and implementation of U.S. Global Change Research Program goals and objectives



The existing global distribution of terrestrial biomes derived from AVHRR data for 1989 (Nemani and Running 1995). These land-cover data sets are used to quantify land-surface characteristics in global climate, hydrology, and carbon-cycling models. Land-cover monitoring is also important for quantifying deforestation/reforestation rates and land-use change and urbanization. EOS will produce a global land-cover product similar to this at 1 km. resolution based on Terra satellite observations.

# The Coming Program (2002-2010): Understanding the Earth System

## STRATEGIC PRIORITIES

- Implement a focused and vigorous research program to answer fundamental questions of Earth system forcing and response
- Fulfill our commitment to the science community to provide long-term (15 years or more) climate records of key Earth observations by:
  - ◆ Providing key systematic measurements as needed beyond the EOS first series via commercial data purchases where these meet science requirements and are cost-effective
  - ◆ Transition of mature, key systematic measurements to the national and international operational satellite systems
- Conduct exploratory satellite missions to probe unfamiliar Earth system processes, such as understanding the role of cloud vertical structure and properties, distributions and origins of aerosols on Earth's climate and its variability, and deformation of the Earth's surface
- Implement an open and distributed information system architecture that will include Principal Investigator processing in the mix of science data processing providers, and tie together diverse creators and users of higher level information products
- Develop an Earth Science Extension Network to exchange information products at the State and local level, and facilitate jointly sponsored applications research to enable broad societal benefit from Earth science knowledge
- Collaborate with operational mission agencies and commercial concerns to demonstrate remote sensing capabilities they want to incorporate in their decision support systems
- Develop technologies and enhance methodologies of instrument calibration to reduce data interpretation errors and improve weather and other Earth system models
- Pursue advanced technology to enable new observational and analysis capabilities and to reduce the size, cost, and development time of systematic and exploratory satellite missions through such means as:
  - ◆ Advanced component development
  - ◆ Advanced information technology
  - ◆ Advanced component and subsystem technology development and demonstration, (e.g., instrument incubator sensor concept development)
  - ◆ In-space technology experimentation & validation (e.g., New Millennium Program)
- Develop and test models and data assimilation processes to bring diverse observations and research to bear on the fundamental Earth science questions
- Support the conduct of scientific assessments of consequences of climate change and global and regional impacts on:
  - ◆ Food and fiber production
  - ◆ Fresh water and other natural resources
  - ◆ Human health and spread of infectious diseases
  - ◆ Planning and development of roads, cities, and other infrastructure

# Science

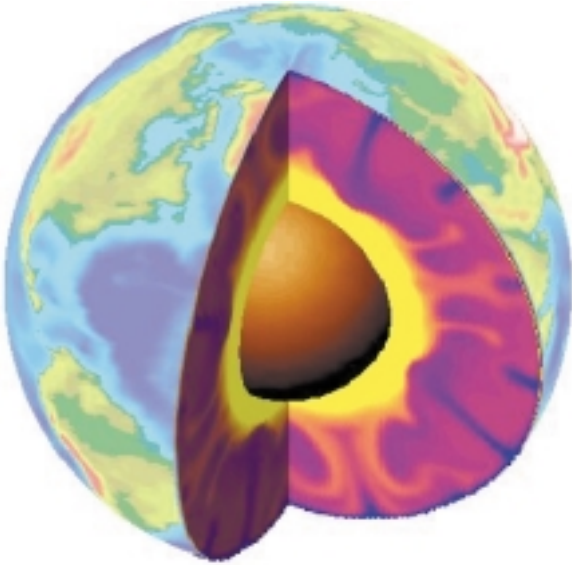
## Goal 1: Observe, understand, and model the Earth system to learn how it is changing, and the consequences for life on Earth

### HOW IS THE EARTH CHANGING AND WHAT ARE THE CONSEQUENCES FOR LIFE ON EARTH?

- *How is the global Earth system changing? (Variability)*
  - ◆ How are global precipitation, evaporation, and the cycling of water changing?
  - ◆ How is the global ocean circulation varying on interannual, decadal, and longer time scales?
  - ◆ How are global ecosystems changing?
  - ◆ How is stratospheric ozone changing, as the abundance of ozone-destroying chemicals decrease and new substitutes increase?
  - ◆ What changes are occurring in the mass of the Earth's ice cover?
  - ◆ What are the motions of the Earth and the Earth's interior, and what information can be inferred about Earth's internal processes?
- *What are the primary forcings of the Earth system? (Forcing)*
  - ◆ What trends in atmospheric constituents and solar radiation are driving global climate?
  - ◆ What changes are occurring in global land cover and land use, and what are their causes?
  - ◆ How is the Earth's surface being transformed and how can such information be used to predict future changes?
- *How does the Earth system respond to natural and human-induced changes? (Response)*
  - ◆ What are the effects of clouds and surface hydrologic processes on Earth's climate?
  - ◆ How do ecosystems respond to and affect global environmental change and the carbon cycle?
  - ◆ How can climate variations induce change in the global ocean circulation?
  - ◆ How do stratospheric trace constituents respond to change in climate and atmospheric composition?
  - ◆ How is global sea level affected by climate change?
  - ◆ What are the effects of regional pollution on the global atmosphere, and the effects of global chemical and climate changes on regional air quality?
- *What are the consequences of change in the Earth system for human civilization? (Consequences)*
  - ◆ How are variations in local weather, precipitation, and water resources related to global climate variation?
  - ◆ What are the consequences of land cover and land use change for the sustainability of ecosystems and economic productivity?
  - ◆ What are the consequences of climate and sea level changes and increased human activities on coastal regions?
- *How well can we predict future changes to the Earth system? (Prediction)*
  - ◆ How can weather forecast duration and reliability be improved by new space-based observations, data assimilation, and modeling?
  - ◆ How well can transient climate variations be understood and predicted?
  - ◆ How well can long-term climatic trends be assessed or predicted?
  - ◆ How well can future atmospheric chemical impacts on ozone and climate be predicted?
  - ◆ How well can cycling of carbon through the Earth system be modeled, and how reliable are predictions of future atmospheric concentrations of carbon dioxide and methane?

# Variability

## How is the global Earth system changing?



The Earth's dynamic interior causes changes in the crust and surface, including earthquakes and volcanoes. NASA's satellites and ground-based sensors measure the Earth's precise shape, and measure land surface deformation in selected areas such as the Los Angeles Basin.

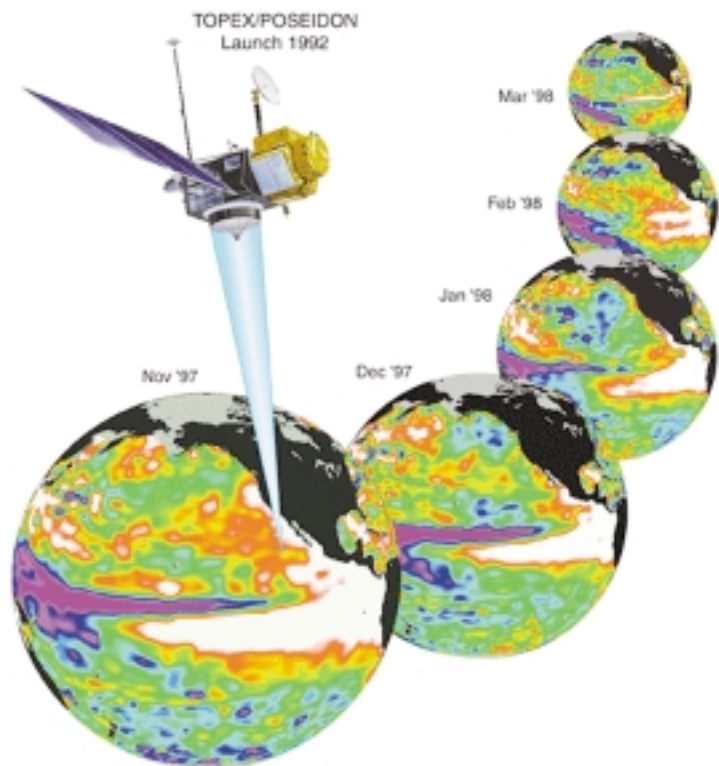
### THE CHALLENGE

The Earth and Sun constitute an exceedingly complex dynamic system that generates variations on all time-scales, from minutes to days in the case of tornadoes and other severe weather disturbances, to many millions of years in the case of tectonic phenomena and erosion that shaped the Earth's landscapes, and the biogeochemical processes that conditioned the Earth's atmosphere and oceans.

### WHAT WE KNOW ABOUT EARTH SYSTEM VARIABILITY

The Earth's climate system exhibits intrinsic variability, as seen in weather systems in the short term, El Niño/La Niña fluctuations in the medium term, and glacial periods (ice ages) in the longer term. Weather satellites designed by NASA and operated by NOAA have extended short term weather forecasts to 3 to 5 days. Ocean radar altimetry measurements enable researchers to track the formation of El Niño and La Niña events, and models are being developed to predict their impact on Earth's climate several months and seasons in advance. Recent research is showing that the flood of aerosols released by urban and industrial pollution suppresses rainfall and snowfall downwind of their sources.

Heat loss from Earth's interior generates variability in the gravity and magnetic fields and causes convective motions deep inside the Earth. These motions drive plate tectonics resulting in earthquakes and volcanoes. Changes in the gravity field also reflect geological processes, such as subsidence, uplift, glacial rebound, and erosion which influence the rate of sea level rise.



El Niño and La Niña affect tropical and mid-latitude weather around the globe. NASA and NOAA instruments track the waxing and waning of these phenomena as part of an effort to predict their occurrence in the future.

# Objective 1.1

## Discern and describe how the global Earth system is changing

### KEY ELEMENTS OF NASA'S RESEARCH PROGRAM OVER THE NEXT DECADE

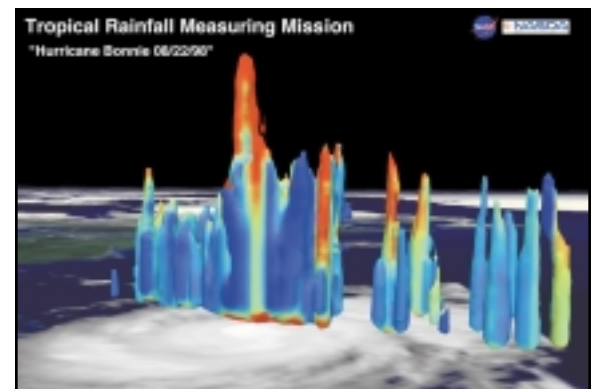
Science Question	Required Knowledge	EOS Era	Thru 2010
How are global precipitation, evaporation, and the cycling of water changing?	Atmospheric temperature Atmospheric water vapor Global precipitation Soil moisture	Aqua Aqua TRMM	NPOESS Bridge mission NPOESS Bridge mission Future global precipitation mission Exploratory soil moisture mission
How is the global ocean circulation varying on interannual, decadal, and longer time scales?	Sea surface temperature Extent of sea-ice Ocean topography Earth's gravity field Earth's center of mass	Aqua Aqua, SeaWinds TOPEX/Jason GRACE Ground networks	NPOESS Bridge mission Exploratory or operational mission Future ocean topography mission Future exploratory gravity mission Ground networks
How are global ecosystems changing?	Ocean color Vegetation Index	SeaWiFS, Terra, Aqua Terra, Aqua	NPOESS Bridge mission NPOESS Bridge mission
How is stratospheric ozone changing, as the abundance of ozone-destroying chemicals decrease and new substitutes increase?	Ozone total column Ozone vertical profile	TOMS, Triana, Aura SAGE III	Future ozone/aerosol total column mission Future ozone/aerosol vertical profile mission
What changes are occurring in the mass of the Earth's ice cover?	Ice surface topography Sea ice extent	ICESat DMSP, QuickSCAT	Future ice altimetry mission Operational systems
What are the motions of the Earth and the Earth's interior, and what information can be inferred about Earth's internal processes?	Earth reference frame Earth's magnetic field Earth's gravity field Strain field	VLBI/SLR networks Magnetometer/GPS constellation GRACE ERS-1/-2	VLBI/SLR terrestrial networks Magnetometer/GPS constellation Exploratory gravity mission Exploratory interferometric SAR mission

### EXAMPLES OF EXPECTED ACCOMPLISHMENTS

- Ocean observation in support of a practical El Niño/La Niña prediction capability by operational agencies
- Seasonal and annual variation in rainfall by region; decadal trend in global rainfall rate
- Quantitative knowledge of variations and trends in the productivity, composition and health of terrestrial and marine ecosystems (including their carbon uptake and output)
- Estimates of ice sheet and glacier thickening and melting, and their mass balance

### EXAMPLES OF PRACTICAL BENEFIT TO THE NATION

- Increased efficiency in agricultural production and decreased losses from seasonal rainfall prediction
- Assessment of crop and fisheries health and distribution
- Assessment of availability of global fresh water resources
- Assessment of future sea level rise



Height of cloud chimneys during Hurricane Bonnie, indicating the distribution of energy within the storm. The highest reach to nearly 60,000 feet. Knowledge of energy distribution within the storm has recently been shown to improve the prediction of storm movement.

# Forcing

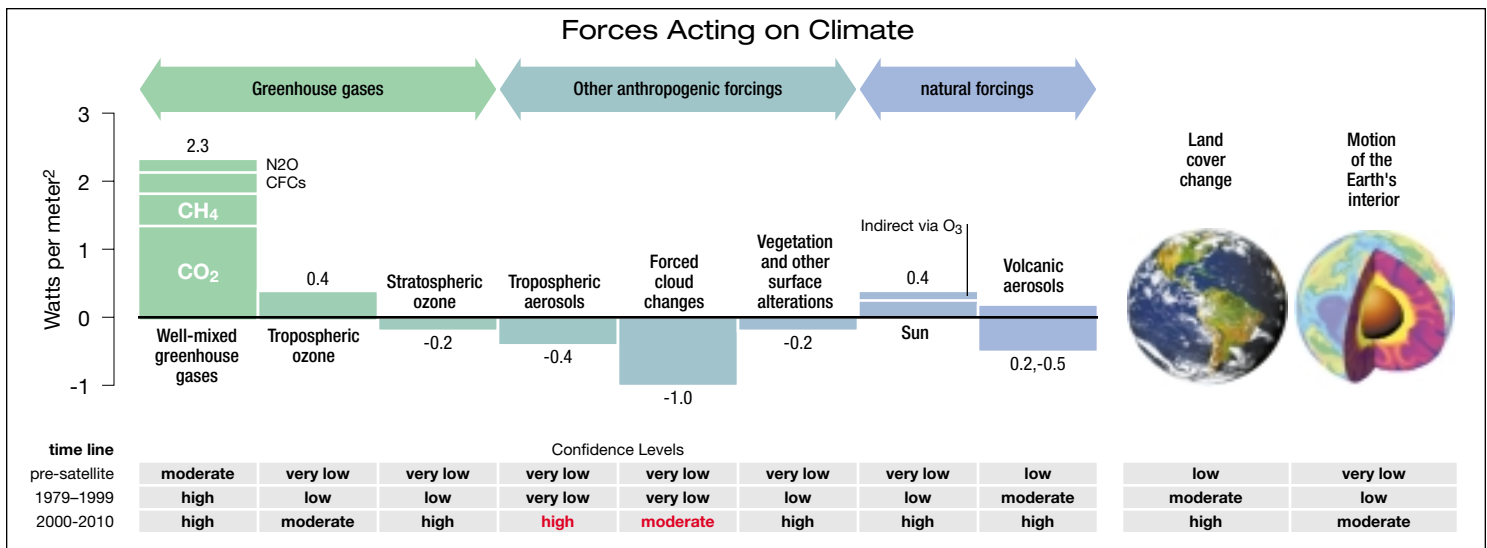
## What are the primary causes of change in the Earth system?

### THE CHALLENGE

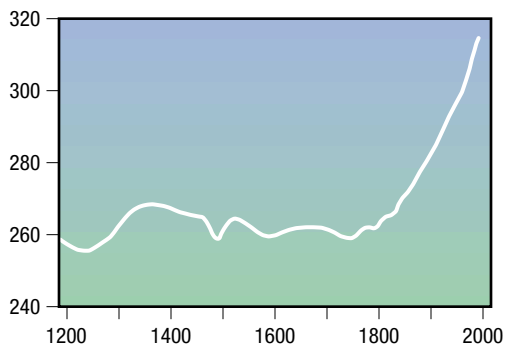
Forces acting on the Earth system are both external and internal, and both natural and human-induced. The larger challenge is to quantify both the natural and human-induced forces accurately enough to detect trends and discern the patterns of change they bring about in climate and ecosystems.

### WHAT WE KNOW ABOUT FORCES ACTING ON THE EARTH SYSTEM

Researchers have identified the key forces acting on climate, and have estimated their comparative contributions to climate change.



**Global Atmospheric CO<sub>2</sub> concentrations**



In recent times, the most significant anthropogenic forcing of the planetary environment has been the modification of the composition of the atmosphere, leading to rising concentrations of a number of reactive and radiation absorbing gases that contribute to depleting the stratospheric ozone layer and to increasing the atmospheric greenhouse effect. Measurements at the Mauna Loa observatory and several other stations have documented a recent upward trend of about 1 percent per year in atmospheric carbon dioxide (CO<sub>2</sub>), amounting to a 30 percent increase in global atmospheric concentration since the beginning of the industrial era. The magnitude of the direct forcing of the climate by tropospheric aerosols remains one of the largest unknown factors in climate research. The release of gases and particulate matter into the atmosphere from volcanic eruptions is also important. Motions of Earth's crust force significant surface deformation and topographic changes that can have major impacts on the land surface.

# Objective 1.2

## Identify and measure primary causes of change in the Earth system

### KEY ELEMENTS OF NASA'S RESEARCH PROGRAM OVER THE NEXT DECADE

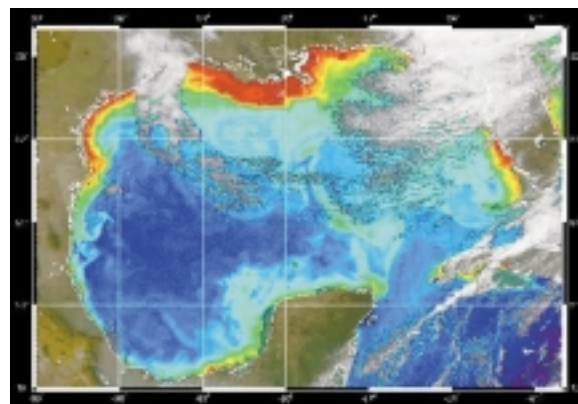
Science Question	Required Knowledge	EOS Era	Thru 2010
What trends in atmospheric constituents and solar radiation are driving global climate?	Total solar irradiance Solar UV irradiance Total aerosol amount Aerosol vertical profile Aerosol properties  Surface trace gas concentration Trace gas sources/total column CO <sub>2</sub>	ACRIMSAT, SORCE UARS, SORCE Terra SAGE III Terrestrial network  Terrestrial network Terrestrial network	Future solar irradiance mission Future solar irradiance mission NPOESS Bridge mission PICASSO, SAGE III (ISS) Terrestrial network, exploratory tropospheric chem mission Terrestrial network Terrestrial network, exploratory space-based system
What are the changes in global land cover and land use, and what are their causes?	Land cover inventory Fire occurrences	Landsat 7, Terra Terra	Domestic and/or international partnerships NPOESS Bridge mission
How is the Earth's surface being transformed, and how can such information be used to predict future changes?	Surface topography Deformation & stress accumulation Gravity and geomagnetic fields Earth reference frame	SRTM ERS-1/-2 Space GPS receivers Surface networks	Exploratory interferometric laser or SAR mission(s) Exploratory interferometric laser or SAR mission(s) Space GPS receivers Surface networks

### EXAMPLES OF EXPECTED ACCOMPLISHMENTS

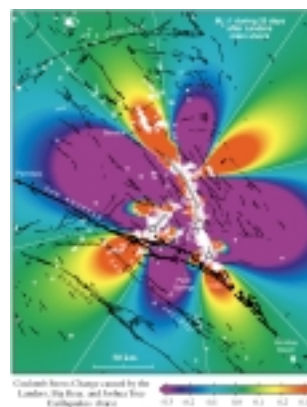
- Each of the identified forces acting on climate will be quantified, with a “high” or “moderate” degree of confidence in its contribution to Earth’s climate
- The principal anthropogenic sources of aerosols and their impacts on Earth’s climate will be quantified
- Quantitative assessment of global marine and terrestrial ecosystems and their contribution to cycling of carbon through the Earth system over time will be made
- A seasonal refresh of the global archive of land cover and change data will be accomplished periodically
- The first measurements of sunrise-to-sunset changes in atmospheric ozone and aerosols, and associated maps of ultraviolet radiation at the surface will be published
- Spatially and temporally continuous measurements of Earth’s changing strain field will be obtained
- Quantitative models of earthquakes and volcanic systems will be developed

### EXAMPLES OF PRACTICAL BENEFIT TO THE NATION

- Economic and policy decisionmakers will have a robust, scientific basis on which to compare alternate courses of action concerning activities that affect or are affected by climate variations and natural hazards
- Regional, State, and local authorities and businesses will have the basic scientific knowledge and geospatial data information products to support their activities in urban, transportation, and agricultural planning and development
- Health officials will have maps of surface ultraviolet radiation to assess associated health risks
- Refined natural hazards maps (e.g., fires, earthquakes, volcanoes) will result in improved building codes and retrofit strategies to mitigate their impact



Phytoplankton concentration in the Gulf of Mexico from SeaWiFS, February 23, 1998. Such data are used by commercial fishing operators and by researchers studying coastal zones and the global carbon cycle.



# Response

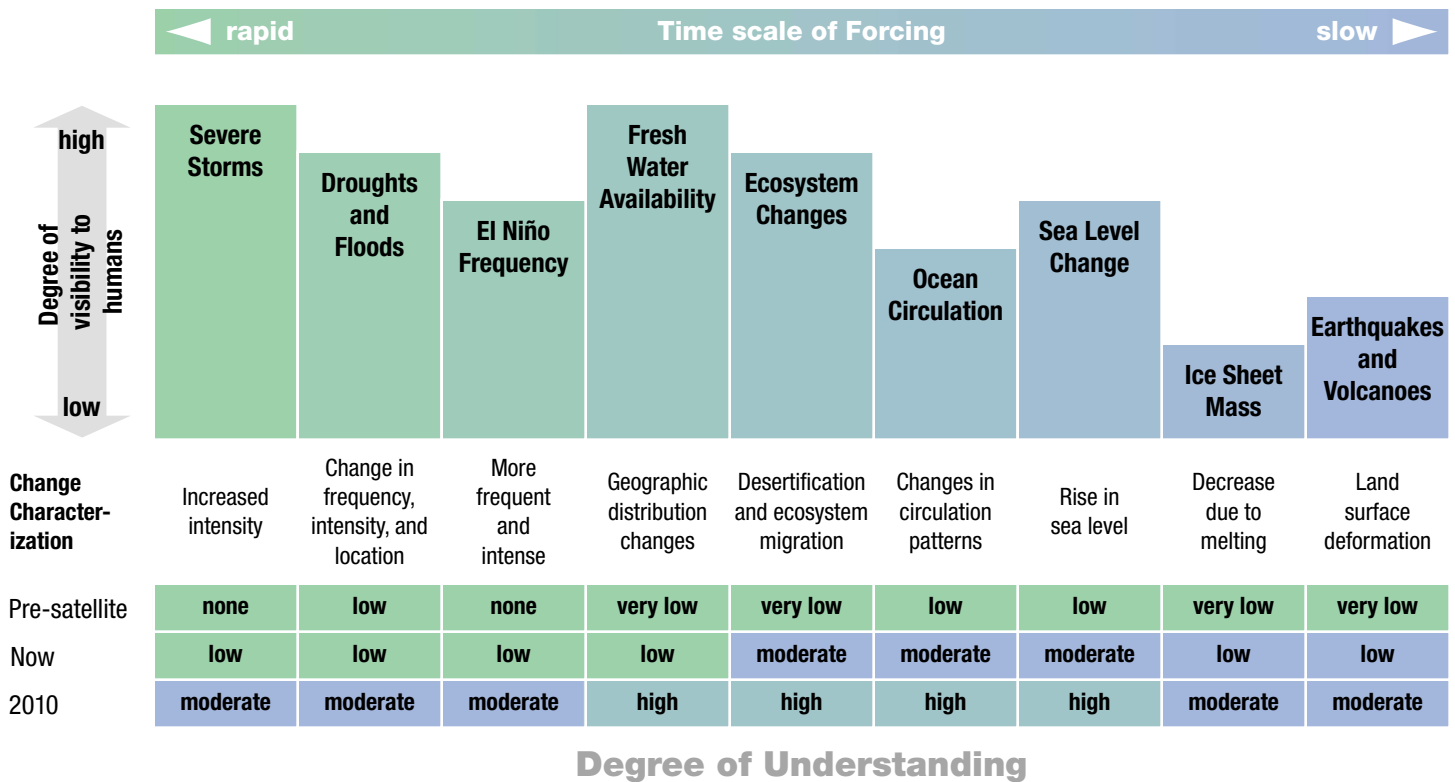
## How does the Earth system respond to natural and human-induced changes?

### THE CHALLENGE

Linking responses to forcing factors is a difficult problem given the large natural variability inherent to the Earth system. Complicating the problem further are the feedbacks—responses to Earth system changes can themselves influence and amplify the responses of the system, as is the case with water vapor in the atmosphere in its effects on temperature. One key to progress is the development of models which couple the ocean and atmosphere and the land and atmosphere in order to probe causes and effects which cross boundaries among Earth system components.

### WHAT WE KNOW ABOUT HOW THE EARTH SYSTEM RESPONDS TO CHANGE

Key Earth system response parameters have been identified, and the time scale of their occurrence and a general characterization of their visibility to people illustrated below.



# Objective 1.3

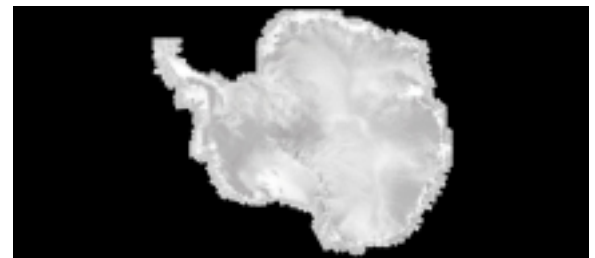
## Determine how the Earth system responds to natural and human-induced changes

### KEY ELEMENTS OF NASA'S RESEARCH PROGRAM OVER THE NEXT DECADE

Science Question	Required Knowledge	EOS Era	Thru 2010
What are the effects of clouds and surface hydrologic processes on Earth's climate?	Cloud system structure Cloud particle properties & dist.  Earth radiation budget Soil moisture Snow cover & accumulation Land freeze-thaw transition	Terra, Aqua  Terra, Aqua, ACRIM  Terra, Aqua Seawinds	NPOESS Bridge mission Cloudsat, PICASSO, future aerosol/cloud radiation mission  Exploratory soil moisture mission Exploratory cold climate mission Exploratory cold climate mission
How do ecosystems respond to and affect global environmental change and the carbon cycle?	Ecosystem vertical structure Marine productivity in coastal regions Carbon sources and sinks	Terra, Aqua	Exploratory vegetation recovery mission NPOESS Bridge mission Exploratory CO <sub>2</sub> column mission
How can climate variations induce changes in the global ocean circulation?	Sea surface salinity Subsurface temperature, currents, salinity	In situ ocean buoys	Exploratory ocean salinity mission In situ ocean buoys
How do stratospheric trace constituents respond to change in climate and atmospheric composition?	Atmospheric properties near tropopause Selected chemical species Selected source gasses	Aura  Aura, SAGE III Surface network	Aura, Future stratospheric chemistry mission  Future stratospheric chemistry mission, SAGE III (ISS) Surface network
How is global sea level affected by climate change?	Polar ice sheet velocity fields	Radarsat	Exploratory interferometric laser or SAR mission(s)
What are the effects of regional pollution on the global atmosphere?	Tropospheric ozone and precursors	Aura	Exploratory tropospheric chemistry mission

### EXAMPLES OF EXPECTED ACCOMPLISHMENTS

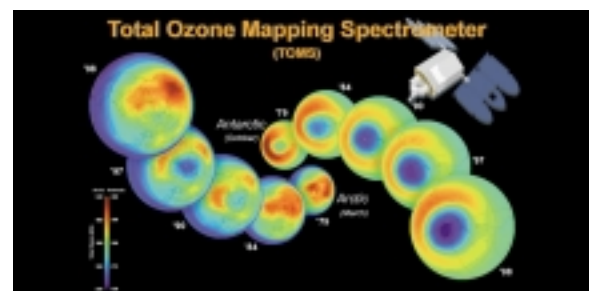
- Over the decade, each of the identified climate responses will be quantified, with a "high" or "moderate" degree of confidence in its impact on climate change
- Understand the chemical impacts of CFC substitutes and the efficacy of the Montreal Protocol on Substances Depleting the Ozone Layer
- Provide global mapping of regional air quality
- First estimate of carbon stocks in forests and oceans globally



The first topographic map of Antarctica, from the NASA collaboration with Canada on Radarsat, reveals how ice moves from the interior to the coast.

### EXAMPLES OF PRACTICAL BENEFIT TO THE NATION

- Seasonal and annual variation in soil moisture for agriculture planning and flood hazard assessment
- Geospatial information and decision support systems to generate fire hazard maps based on fuel-load and climate conditions for forest and rangeland management
- Scientific basis for air quality management decisions



Ozone levels in the Arctic now appear to be where those in the Antarctic were when it became a concern.

# Consequence

## What are the consequences of change in the Earth system for human civilization?



Landsat 7 images of the Outer Banks of North Carolina show the river discharge effects of Hurricane Floyd (Sept. 23, 1999).

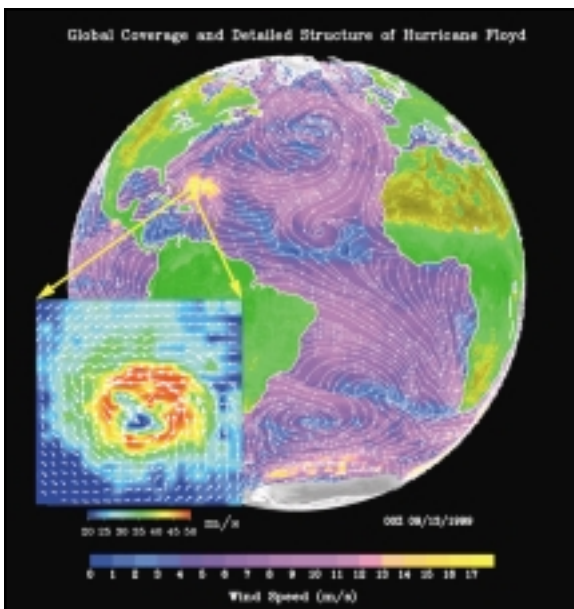
### THE CHALLENGE

Small changes in the global distribution of Earth system properties, such as mean surface temperature or sea-level pressure, can entail changes of much greater significance in regional weather, productivity patterns, water resource availability, and other environmental attributes. We already know, for example, El Niño warm ocean water episodes shut down regional marine productivity and broader climate patterns. El Niño events appear to be correlated with fewer hurricanes in the Atlantic but more typhoons in the Pacific. La Niña climate episodes, manifested by cooling of surface waters in the eastern tropical Pacific ocean by a few degrees Celsius, appear to be associated with more active hurricane seasons in the Atlantic basin, featuring more frequent and generally stronger tropical cyclones than normal years.

### WHAT WE KNOW ABOUT THE CONSEQUENCES OF CHANGES IN THE EARTH SYSTEM

Frequency of extreme rainfall events (greater than two inches per day) has increased in recent years at most locations, although the causes have yet not been unambiguously revealed.

The growing season appears to have lengthened in much of the mid-latitude northern hemisphere by about 10 to 14 days over the next 30 years.



QuikSCAT ocean surface winds data enables scientists to study severe storms in their broader climate context. These same data improve marine weather forecasts and predictions of storm movement.

# Objective 1.4

## Identify the consequences of changes in the Earth system for human civilization

### KEY ELEMENTS OF NASA'S RESEARCH PROGRAM OVER THE NEXT DECADE

Science Question	Required Knowledge	EOS Era	Thru 2010
How are variations in local weather, precipitation and water resources related to global climate variation?	Global precipitation Ocean surface winds  Meteorological properties around storms Lightning rate River stage height & discharge rate	TRMM Seawinds  GOES  LIS Jason	Future global precipitation mission Future national/international cooperative mission GOES w/improvements  UNESS, Transition to operational missions Future national/International cooperative mission
What are the consequences of land cover and land use change?	Primary productivity Land cover inventories	Terra Landsat 7, Terra	NPOESS Bridge mission Domestic and/or international partnership
What are the consequences of climate and sea level changes and increased human activities on coastal regions?	Coastal region properties & productivity	Landsat 7, Terra	Commercial sources of data and/or exploratory missions

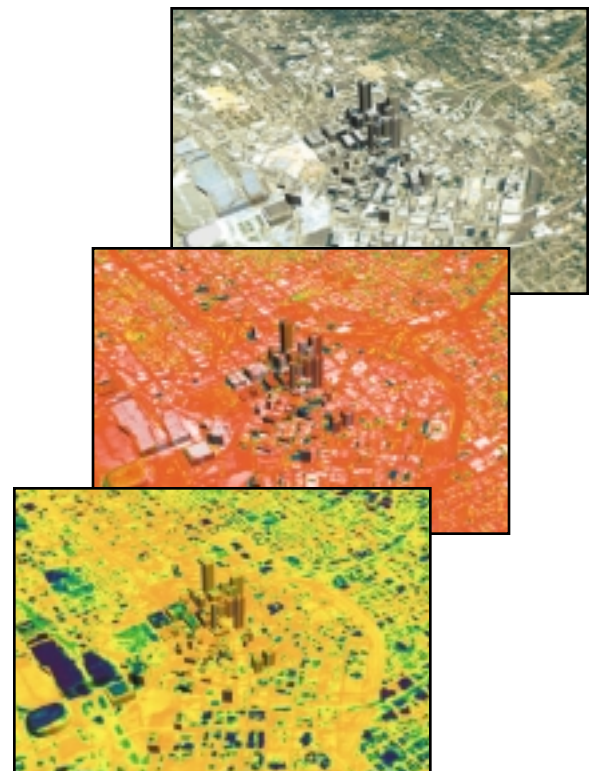
### EXAMPLES OF EXPECTED ACCOMPLISHMENTS

- High resolution structure of the global ocean surface wind field through operational satellites to enhance short-term weather forecasts
- Fully interactive ecosystem-climate models to assess impacts of various climate change scenarios on ecosystems responses and impact on the goods and services they provide
- Understanding the year-to-year variations in net primary production of terrestrial ecosystems and regional agricultural and forest productivity
- Quantitative assessments of global land cover change, and assessments of consequences of land use change
- Understanding the exchanges of nutrients and sediments between the land and coastal oceans worldwide

### EXAMPLES OF PRACTICAL BENEFIT TO THE NATION

State and local planning authorities will have geospatial-based information and necessary tools to aid in decisionmaking for such areas as coastal zone management, transportation and utility planning, and a host of livability issues.

Human health organizations will have access to geospatial and health information and data analysis and visualization tools to assess the consequences of climate change on the spread of vector borne diseases.

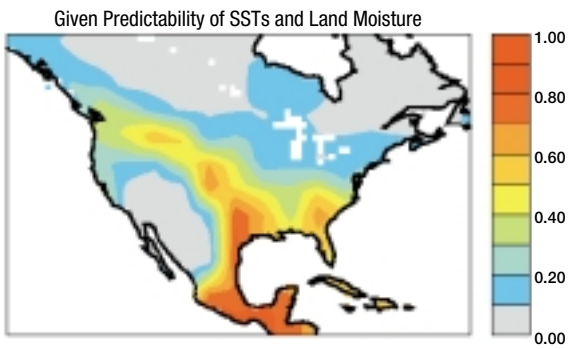
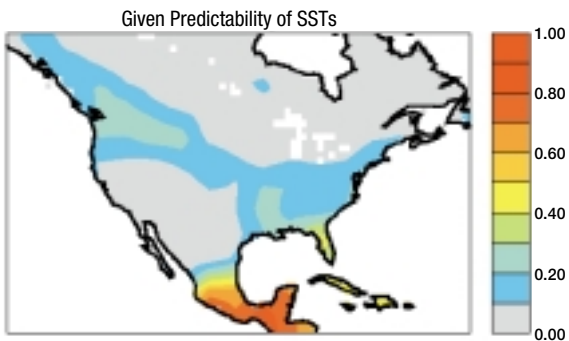


**URBAN HEAT ISLAND EFFECT IN ATLANTA:** These data were collected May 11 and 12, 1997. While daytime air temperatures on that date were only about 80 degrees, surface temperatures reached as much as 118 (F); nighttime air temperatures hovered between 50 and 55, but due to the heat sink, surface temperatures hung on as high as 75 degrees.

# Prediction

## How well can we predict future changes in the Earth system?

### Index of Precipitation Predictability (JJA):



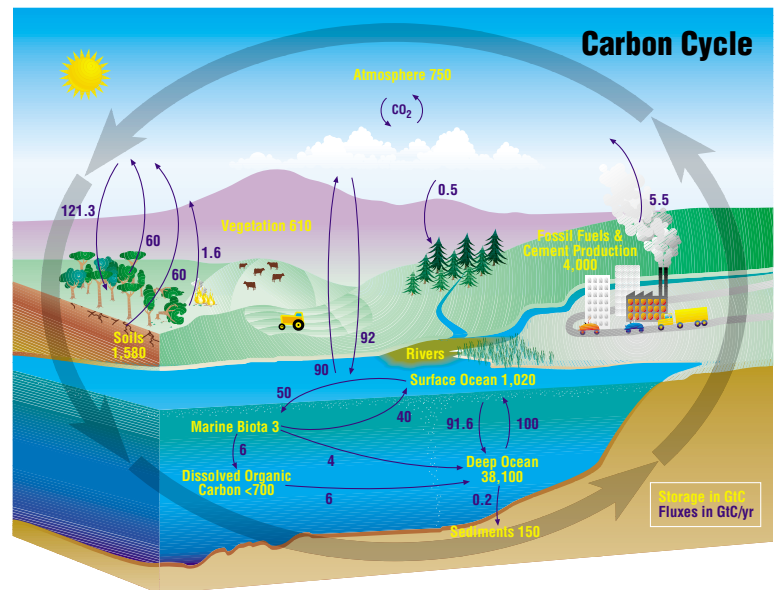
Accurate knowledge of soil moisture would greatly improve predictability of precipitation. NASA has used aircraft-based instruments to demonstrate the feasibility of soil moisture measurement before pursuing a space-based system.

### THE CHALLENGE

The overarching purpose of Earth system science is to develop the knowledge basis for predicting future changes in the coupled physical, chemical, geological, and biological state of the Earth and assessing the risks associated with such changes. Of particular interest are changes in physical climate on the time scale of a human generation, e.g. changes in the composition and chemistry of the atmosphere, and changes in biogeochemical cycles and primary productivity. A first step towards predicting the future of the Earth system is building a capability to simulate realistically the present state and short-term variations of the global environment.

### WHAT WE KNOW ABOUT THE PREDICTABILITY OF FUTURE CHANGES?

Researchers have described the major cycles in the Earth system, including the water and carbon cycles shown here, and have attempted to quantify the various components in each. This understanding is represented in a variety of climate models which are initialized with data from satellites and other sources. Current research is focused on coupling models of the key Earth system components, e.g., ocean-atmosphere and land-atmosphere interactions to represent larger segments of the climate system. Research over the next decade is aimed at filling gaps in our understanding and reducing the significant uncertainties in our current understanding.



The carbon cycle—how carbon circulates among the land, atmosphere, and oceans—is a major focus of climate change research.

# Objective 1.5

## Enable the prediction of Earth system changes that will take place in the future

### KEY ELEMENTS OF NASA'S RESEARCH PROGRAM OVER THE NEXT DECADE

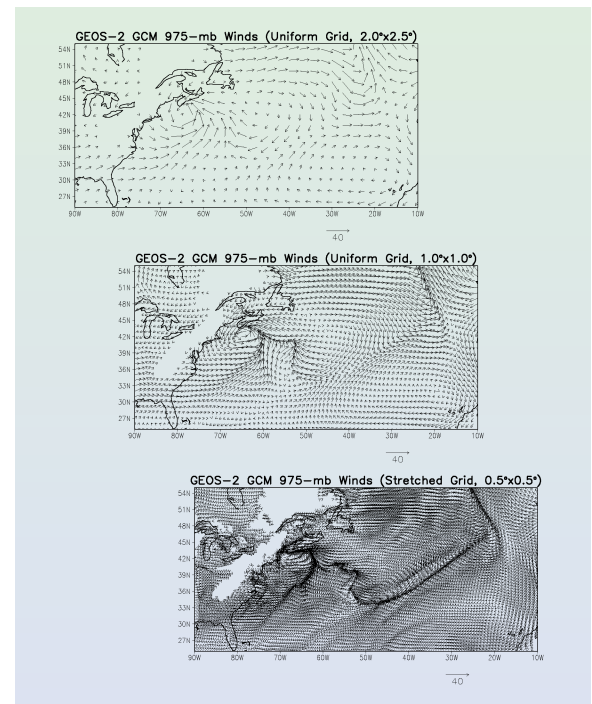
Science Question	Required Knowledge	EOS Era	Thru 2010
How can weather forecast duration and reliability be improved by new space-based observations, data assimilation, and modeling?	Tropospheric winds Ocean surface winds Soil moisture Sea surface temperature	Sea winds  Operational satellites	Domestic and/or international partnership Future national/international cooperative mission Exploratory soil moisture mission Operational satellites
How well can transient climate variations be understood and predicted?	Ocean surface winds Soil moisture Sea surface temperature Sea level height Deep ocean circulation	Seawinds  Aqua Jason In situ measurements	Exploratory or operational mission Exploratory soil moisture measuring mission NPOESS Preparatory Project Future national/international partnership in situ measurements
How well can long-term climatic trends be assessed or predicted?	Assimilation of most of the data from these missions into models	Improve and apply coupled climate system models	Same, but with increased resolution, and regionalization of global predictions
How well can future atmospheric chemical impacts on ozone and climate be predicted?	Assimilation of atmospheric data into models	Improve and apply atmospheric models with chemical constituent transport and reactions	Same, but with increased resolution; model regional aerosols including indirect effect on clouds and albedo
How well can cycling of carbon through the Earth system be modeled, and how reliable are predictions of future atmospheric concentrations of carbon dioxide and methane?	Estimates/scenarios of fossil fuel consumption, methane generation, etc., from DOE	Couple carbon cycle models to climate system model and use to project future CO <sub>2</sub> & climate Develop similar for methane	Improve modeling capability to make future projections of CO <sub>2</sub> , methane, and resulting climate change

### EXAMPLES OF EXPECTED ACCOMPLISHMENTS

- Incorporation of cloud effects in regional climate change models
- Assimilation of ocean winds, sea surface temperature, and precipitation radar measurements into climate and weather forecasting models
- Incorporation of tropospheric winds measurements into operational weather forecasting systems
- Demonstrate enhanced accuracy of 3- to 5-day weather forecasts
- Significantly improve knowledge of the sources and sinks of carbon as it circulates among the land, atmosphere, and oceans
- Acquisition and analyses of geophysical data to significantly improve assessments of earthquake and volcanic risks

### EXAMPLES OF PRACTICAL BENEFIT TO THE NATION

- Demonstrate extended range of weather prediction to 7–10 days
- Expanded ability to assess ecosystem health, with related benefits such as disease vector prediction
- Scientific basis for assessing impacts of human activities on Earth's climate and ecosystems

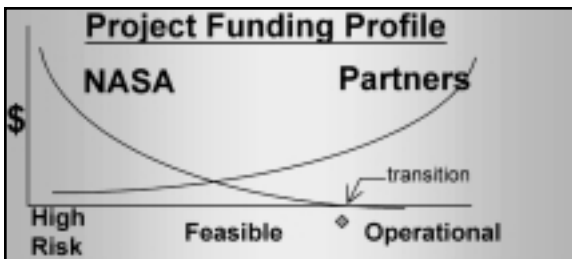


Better models run on faster computers can derive more precise prediction of storm fronts based on satellite observations.

# Applications

## Goal 2: Expand and accelerate the realization of economic and societal benefits from Earth science, information, and technology

The Enterprise and its community stakeholders identified these areas where Earth science at NASA can make a direct, substantial contribution to the Nation's economy and society.



### Resource Management

- Agriculture
- Range lands
- Forestry
- Fisheries

### Community Growth

- Transportation
- Infrastructure
- Quality of life

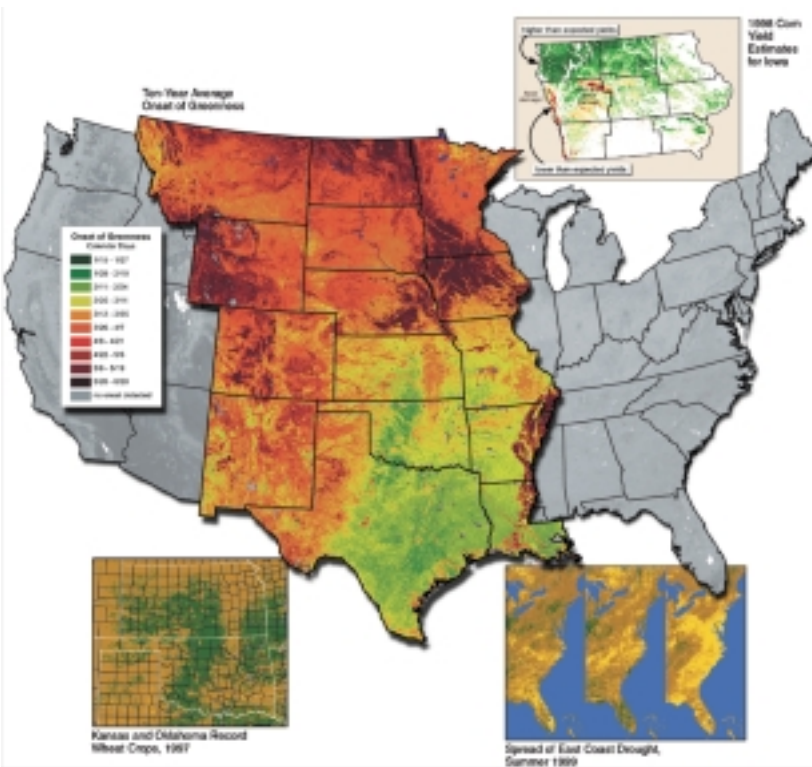
### Disaster Management

- Natural hazards
- Environment and health

### Environmental Quality

- Air and water quality
- Land use/land cover change

The Applications and Education component of the Earth Science Enterprise works to assess and prioritize applications and educational requirements against ESE's capabilities and help transform science and technology results into improved public policy, operations, and commercial opportunities. This activity is structured around three functional lines:



The **Applications** group will focus on understanding the priority issues that face public and private sector decision-makers, and determining how these issues can be addressed by the scientific and technical capabilities of ESE.

The **Education** group will stimulate broad interest in and understanding of Earth system science, research technologies, and applications, and will encourage young scholars to consider careers in science and technology.

The **Outreach** group will focus on providing information to decisionmakers and stakeholders concerning ESE results, the status of projects, and the benefits derived from applications. Outreach will also act as a conduit back to ESE concerning public and commercial needs, requirements, and expectations.

The Earth Science Enterprise pursues applications research and demonstration projects in partnership with other agencies, State and local governments, industry, and academia. We provide the cutting-edge science and technology, and our partners adapt them for their products and services. Successful projects become self-sustaining, and NASA moves on to develop the next set of applications.

# Objective 2.1

## Applications

Turn ESE scientific and technical capabilities into practical tools for solving real world problems.

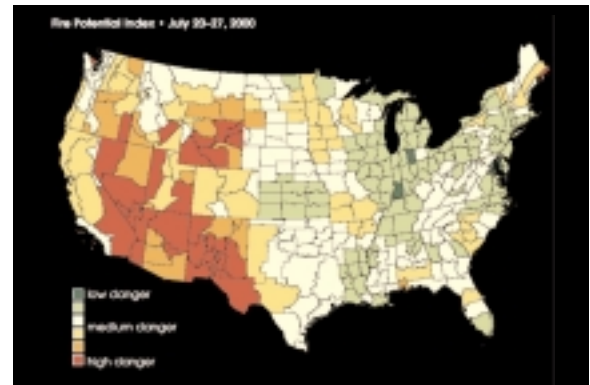
Over the past 10 years, NASA has been successful in stimulating the development of a robust U.S. commercial remote sensing industry, now measured in billions instead of millions of dollars in annual revenues. NASA now engages industry as a partner along with academia and other Federal, State and local agencies to demonstrate new applications of remote sensing data to practical problems.

**Regional Applications**—NASA is creating a program to foster the development and demonstration of applications of geospatial data to a wide variety of State and local uses. This program is national in scope, employs merit-based selection, and is implemented via collaborative partnerships with user organizations.

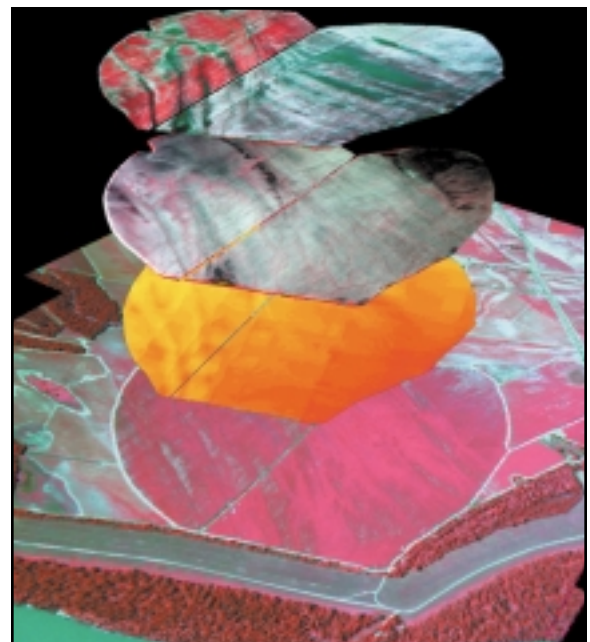
**Natural Hazard Applications**—In partnership with the Federal Emergency Management Agency, NASA is pioneering the use of satellite observations and modeling of natural phenomena for hazard vulnerability assessment. High resolution terrain mapping systems are being used to produce more accurate flood insurance rate maps for the National Flood Insurance Program.

### EXAMPLES OF EXPECTED ACHIEVEMENTS

- Within the next 5 years:
  - ◆ ESE results are shown to benefit decisionmaking in areas such as environmental quality, resource management, community growth, and disaster management
  - ◆ A regional infrastructure that coordinates and maximizes the benefit of ESE programs has been implemented across the United States
  - ◆ ESE science and technology results are being applied to support regional and national assessments of climate
- Within the next 10 years:
  - ◆ Results of regional Earth science applications have been implemented nationwide in community-based environmental programs, multi-jurisdictional hazard mitigation efforts, and by sustainable community organizations



This image shows fire danger around the United States, based on data collected between July 20–27, 2000. (The animation shows a sequence of eight-day measurements, running from April 28 to July 27, 2000.) Red areas indicate where fire potential is greater and green areas show places where the threat is lower. This fire potential map is based on the Soil Moisture Index (SMI). SMI is derived from temperature and vegetation measurements taken by NOAA's satellite-based Advanced Very High Resolution Radiometer (AVHRR).



A remotely sensed image of a Mississippi cotton field demonstrating the use of geospatial information in determining the health of the field, and dictates where, when, and how much water (and eventually, fertilizer and pesticides, should be applied).

# Objective 2.2

## Education

Stimulate public interest in and understanding of Earth system science and encourage young scholars to consider careers in science and technology



Earth Science Education activities focus on communicating the results of ESE through non-formal/informal learning venues and through formal classroom venues. These activities will include creation of ESE content materials for these venues, development of special education programs that amplify the efforts of ESE and stimulate broad awareness and understanding, and the identification of new skills and training that is required to incorporate the rewards of ESE into the fabric of our everyday life.

The Education program aims to:

- Increase public awareness and understanding of how the Earth functions as a system and NASA's role in enabling development of that knowledge
- Enable the use of Earth science information and results in teaching and learning at all levels of education
- Build capacity for productive use of Earth science results, technology, and information in resolving everyday practical problems

### EXAMPLES OF EXPECTED ACCOMPLISHMENTS

- In 5 years:
  - ◆ At least 20 leading undergraduate institutions in education (K-12) are accredited to certify future High School science educators in Earth system science
  - ◆ 10 of the 50 states have a middle school or a high school graduation competency requirement in Earth science and 5 percent of the respective teachers are certified in this field
  - ◆ 20 percent of the American adult populace knows of an Earth system science phenomenon or an applied use and they know that NASA enables this work
  - ◆ A prototype accreditation program, national in scope, exists for undergraduate or vocational instruction of Earth remote sensing principles and techniques, with a companion professional certification program for individual practitioners (basic to advanced, plus areas of expertise).
- In 10 years:
  - ◆ At least 30 leading undergraduate institutions in education (K-12) are accredited to certify future high school science educators in Earth system science
  - ◆ 20 of the 50 states have a middle school or a high school graduation competency requirement in Earth science and 30 percent of their teachers are certified in this field
  - ◆ SAT or ACT tests ask questions on key concepts in Earth system science
  - ◆ 30 percent of the American adult populace knows of an Earth system science phenomenon or an applied use and they know that NASA enables this work
  - ◆ A national accreditation and certification program in Earth remote sensing in place
  - ◆ 10 percent of the Nation's 4-year masters granting universities and colleges are accredited in remote sensing instruction, and 5 percent of two-year institutions are accredited. Five percent of practitioners using remote sensing in the workplace are certified.

# Technology

## Goal 3: Develop and adopt advanced technologies to enable mission success and serve national priorities

### Advanced Technologies

Science-driven advances in technology pave a crucial pathway on the Enterprise's roadmap toward a proactive Earth system prediction capability. The Enterprise seeks technology solutions to both lower the cost of meeting existing observing requirements and make possible measurements that have never been made. NASA is both a supplier of and customer for advanced technologies, provoking and leveraging three ongoing technology revolutions to shape the future of Earth observation.

**Geospatial:** New sensor technologies are making new kinds of observations and data possible. Where passive remote sensing systems (e.g., Landsat) yield two-dimensional imagery, active remote sensing systems (radars and lidars) enable three-dimensional views of the Earth's surface and atmosphere. We can begin to see beyond active sensors to "photon-less" sensors that measure gravity and magnetic fields. These will allow us to "see" the internal structure of the Earth. With such tools we could study changes in the world's fresh water aquifers, make reliable predictions of volcanic eruptions, and even attempt 1- to 5-year prediction of earthquake activity at the neighborhood level. To go with new sensor types, the geospatial revolution also offers new vantage points. Sensors now flying in low Earth orbit can be migrated to geostationary orbit, or even to L1 and L2 a million miles away. These vantage points offer instantaneous, full-time continental or global views, in contrast to the narrow slices and infrequent revisit times available from low Earth orbit. Finally, the geospatial revolution will include networks of sensors, working in tandem to form intelligent, reconfigurable constellations that can respond to rapidly emerging events on Earth, or recover from failures on orbit. We will demonstrate this "sensorweb" concept in the EOS era by 'formation flying' several EOS satellites and processing the data as if the formation were a single "superinstrument."

**Computing:** The computing requirements for such a system will be enormous, growing from today's terabytes (10<sup>12</sup>) to tomorrow's petabytes (10<sup>15</sup>) of data per day. Industry will provide the advances in computing; NASA's job will be to put these capabilities in space to enable on-board data processing and data compression. NASA will also need to do the software design that will allow these high performance computing machines to run the coupled Earth system models that make prediction possible. We want to help drive weather forecasting, for example, to the theoretical limits of prediction (about 14 days), rather than be limited by the capacity of computers to handle the large volumes of data and numerous complex model calculations required.

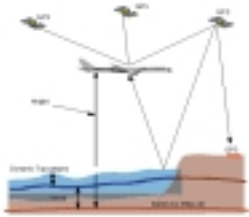
**Communications:** Advanced communications are also needed to enable broad access to knowledge. Our goal is to enable Earth system prediction that is broadly available in society. In our space-based observing context, it could mean on-board data fusion to allow transmission of tailored information products directly to a user's desktop at no more than the cost of today's international telephone call. As with computing, many of the tools will come from industry. NASA's role will focus on those aspects with particular utility to Earth science, such as knowledge presentation via new visualization techniques like immersive environments, and knowledge generation via data mining.



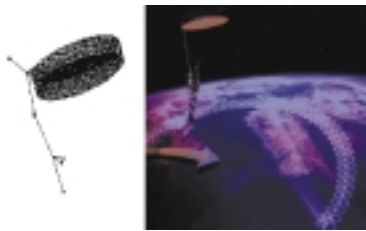
# Objective 3.1

## Observing Technologies

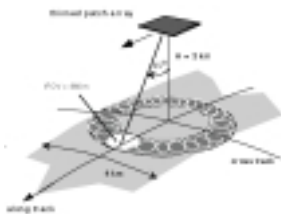
Develop advanced technologies to reduce the cost and expand the capability for scientific Earth observation



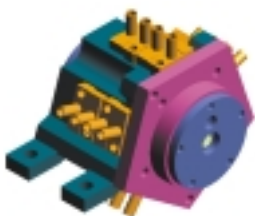
**GPS-based Oceanographic and Atmospheric Low Earth Orbiting Sensor (GOALS).** Technology area: performing surface altimetry using GPS reflections.



**Spaceborne Microwave Instrument for High Resolution Remote Sensing Using a Large Aperture Mesh Antenna.** Technology area: 6-meter deployable mesh reflector.



**Two Dimensional Synthetic Aperture Radiometer for Microwave Remote Sensing from Space.** Technology area: 6x10 meter deployable thin array antenna, small digital correlators.



**Efficient, Conductively-Cooled, Double-Pulsed 2-micron Laser Transmitter for Multiple Lidar Applications.** Technology area: high thermal conductivity C-C composit dissipaters.

Instrument development strategy will focus on new measurement approaches that will enable more capable science missions. Space platform development supporting the instruments will focus on reducing volume, weight, and operational complexity. Furthermore, when these technologies are developed prior to a mission implementation phase, costs and schedule uncertainties and risks can be significantly reduced. Development strategies include:

- Smaller, smart detector arrays and passive sensing systems that reduce sensor subsystem mass and power, to simplify calibration, integration, and operation. These will make use of the entire information content of the entire electromagnetic spectrum
- Instrument architectures such as active sensors for space-based laser, lidar, and radar applications with improved lifetime, efficiency, and performance and with reduced mass, volume, and cost
- Platform architectures that provide significant reductions in life-cycle costs by decreasing mass, volume, power, and operations complexity and increases in autonomy of on-board operations
- Techniques and algorithms that enable formation flying of small scientific spacecraft
- Advanced miniaturization that will enable smaller, more capable sub-orbital and surface-based platforms
- Develop technology demonstration and validation testbeds based on airborne, sub-orbital, and space-based platforms.

For example, the Instrument Incubator Program is intended to reduce the risk of innovative, high-payoff technologies that will be incorporated into future scientific instrument subsystems and systems. The New Millennium Program provides an on-orbit validation testbed for new technologies that have matured to a level where the unique conditions of space are needed to assess their feasibility prior to their infusion into science missions.

# Objective 3.2

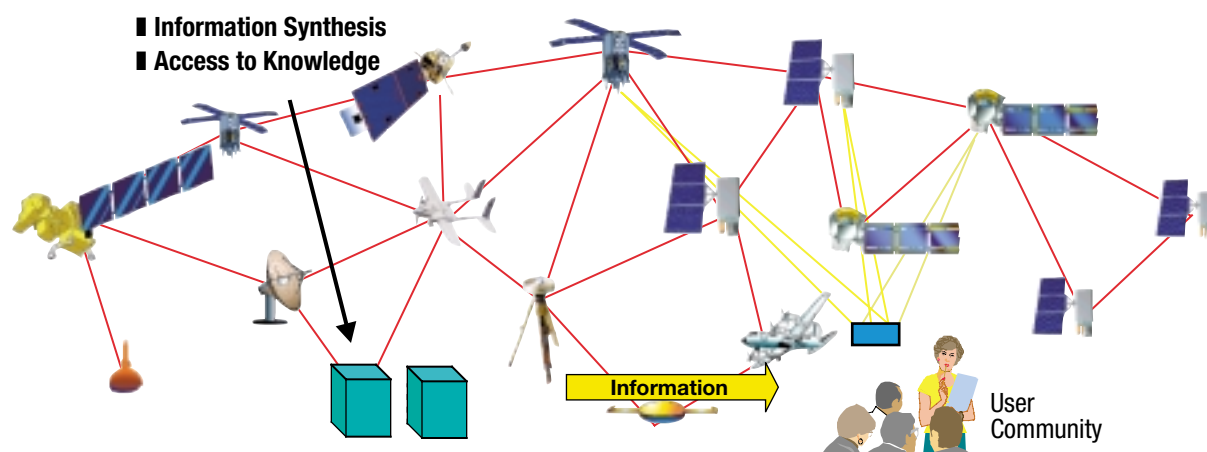
## Information Technologies

Develop advanced information systems for processing, archiving, accessing, visualizing, and communicating Earth science data

Advanced computing and communications concepts that permit the transmission and management of terabytes of data are essential to the ESE's vision of a global observational network. Information provided to a nation-wide community of users will result in significant leaps of knowledge of Earth system dynamics benefiting a global community. This advanced information network, for example, will enhance and enable data-gathering and physical-modeling activities intended to distinguish between natural and human-induced changes in the Earth system.

The information systems element of the ESE Technology Program focuses on an “end-to-end architecture” approach to advance technologies—from the space segment where the information pipeline begins to the end user where knowledge is advanced. Developments in hardware and software technologies include:

- On-board hardware and software architectures that introduce new mission operations capabilities such as intelligent platform and sensor control. This program element is coordinated with the NASA Space Operations Management Organization (SOMO)
- Effective approaches for linking multiple data sets and extracting and visualizing Earth system data and information
- Tools to expand access to Earth science information by commercial and local users in forms suitable for their own applications
- Translation of High Performance Computing and Communications (HPCC) concepts into elements of the future space/ground communications infrastructure



# Objective 3.3

## Partnerships for Monitoring and Prediction

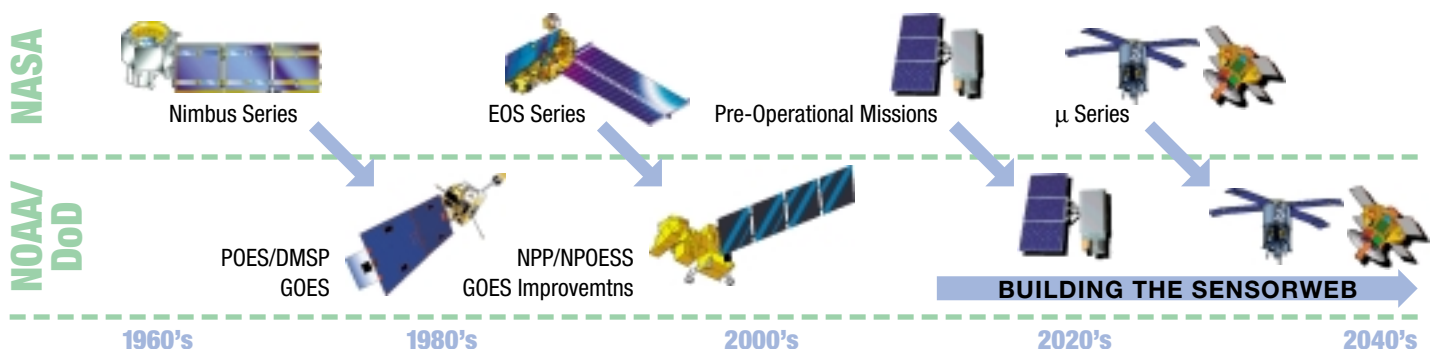
Partner with other agencies to develop and implement better methods for using remotely sensed observations in Earth system monitoring and prediction

As a research and technology Agency, NASA provides new tools and knowledge to enable improved assessment and prediction of Earth system changes and impacts. NASA began with the first weather satellites, and continues today with satellites that monitor globally the state of atmosphere, oceans, land, and ice from space. Other agencies, most prominently NOAA and USGS, adopt these capabilities to improve their operational weather forecasting and monitoring of land surface changes, respectively. NASA's job is to help them do it more effectively and efficiently based on new and advanced technologies.

For example, NOAA and DoD are working to converge their separate weather satellite programs. NASA is currently partnering with them to develop new instruments for the converged National Polar-orbiting Operational Environmental Satellite System (NPOESS). These will fly first on the NPOESS Bridge mission, which will serve both to extend science measurements for NASA and to mitigate technology risks prior to infusion into the NPOESS. Such enhanced capabilities will enable enhanced accuracy and duration of short-term weather forecasts as well as establish key observations required for long-term climate studies and monitoring.

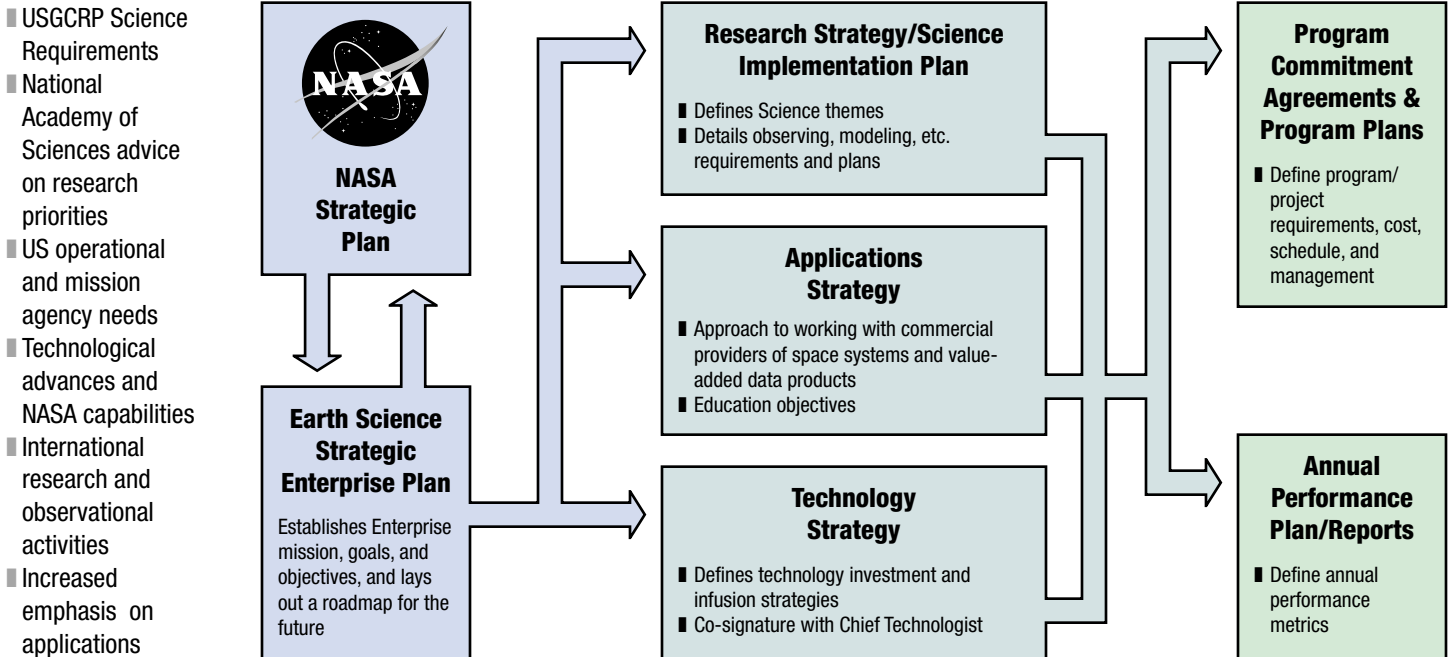
NASA is also working with USGS on the acquisition of Landsat and other land surface remote sensing technologies. For example, NASA is partnering with USGS and NSF on GPS arrays to monitor the motions of continents and faults leading to earthquakes and volcanoes.

As the business of space-based Earth observations grows in the private sector, the Technology Program will emphasize the development of the sensors, space architectures, and information systems that underpin the ability of commercial flight systems to meet some of the Enterprise's needs. An area of particular interest is the pursuit of partnering possibilities with domestic and international organizations investing in micro-satellite technology to stimulate interest in a "Sensor-web" approach to a global Earth observing network.



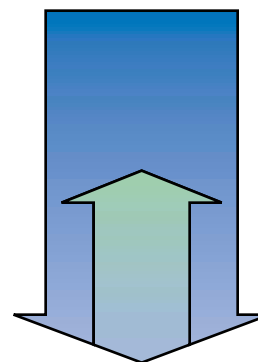
# ESE Strategic Implementation Approach

## TRANSLATING DIVERSE REQUIREMENTS INTO INTEGRATED PLANS



- NASA's Earth Science Enterprise is committed to the broadest accessibility and use of Earth science data. The principals implementing this policy are contained in Appendix N: ESE Statement on Data Management
- ESE seeks to purchase science data from commercial sources when these data meet science requirements and are cost-effective. Statements of commercial data purchase options and preferences will be included in all future Announcements of Opportunity. ESE will establish rights to distribute data from commercial science data purchases according to mutually acceptable terms.
- ESE is committed to competition in developing ESE missions and funding research
- ESE will pursue commercial, interagency, and international partnerships to develop missions, ensure sustained long-term observations, and conduct research

### Science Priority Criteria



- Science Return
- Benefit to Society
- Mandated Program
- Appropriate for NASA
- Partnership Opportunity
- Technology Readiness
- Program Balance
- Cost/Budget Context

### Implementation Priority Criteria

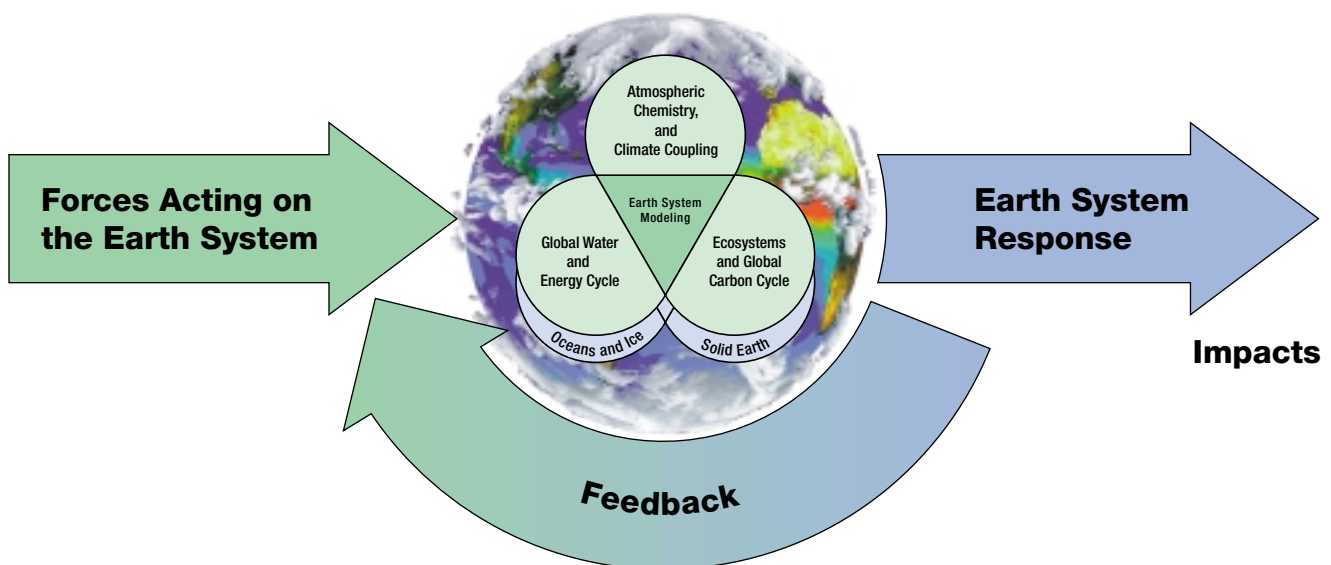
NASA's selection of priorities involves both scientific needs and implementation realities. Purely scientific considerations are followed by considerations in a science-related context, such as benefits to society. Implementation considerations such as cost and technology readiness impact the order in which projects are pursued and the final shape they may take.

## The Earth Science Enterprise observing and information system capabilities serve to accomplish science and applications goals.

Three types of satellite missions will be developed to provide observations required to answer ESE's science questions:

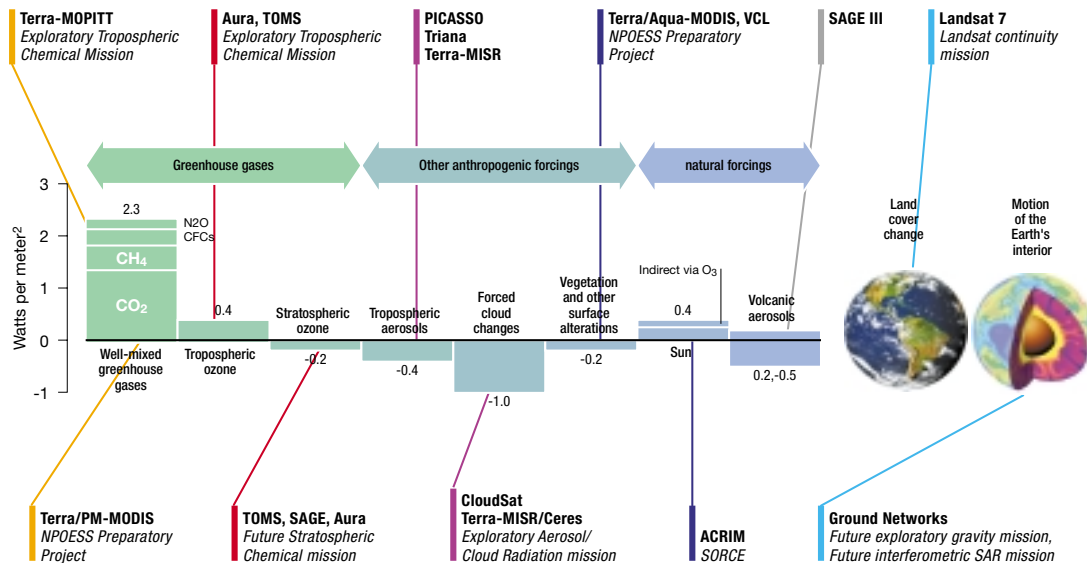
- Systematic Missions (e.g., Landsat, EOS follow-ons)
  - ◆ Meets NRC goal "Priority must be given to identifying and obtaining accurate data on key variables carefully selected in view of the most critical scientific questions. . ." emphasizing those parameters that cannot be inferred from other independent parameters
  - ◆ Strong focus on connection between successive data sets, calibration, and validation over lifetime of the mission
  - ◆ Typically involve technology evolution rather than revolution
  - ◆ Preferably but not necessarily continuous (depends on variability and calibration)
- Exploratory Missions (e.g., Earth System Science Pathfinders)
  - ◆ One-time missions designed to address a focused set of scientific questions, frequently measuring related parameters for closure tests
  - ◆ May involve first application of advanced technology to address question in new way
- Operational Precursor and Technology Demonstration Missions (e.g., tropospheric winds, New Millennium Program)
  - ◆ Invest in innovative sensor technologies and develop more cost-effective versions of pioneer scientific instruments
  - ◆ Identify "bridging" missions for transition between research and operational systems
  - ◆ Close cooperation between NASA and operational agency is needed to fulfill both research and operational needs
  - ◆ Result in fulfilling "long-term" scientific observational needs

The challenge of managing the data coming down from these satellites and generating from them the information products is an ongoing one. The Earth Observing System Data and Information System (EOSDIS) performs this function for EOS. A federation comprising the EOSDIS Distributed Active Archive Centers, Earth Science Information Partners, and Regional Earth Science Applications Centers serve specialized needs of science and applications users. As the march of information and communications technology continues, ESE must evolve its data and information system services approach. Work is underway on a data and information system services concept for the next decade which builds on the capabilities being put in place today, and evolves to leverage the science and technology advances of tomorrow.

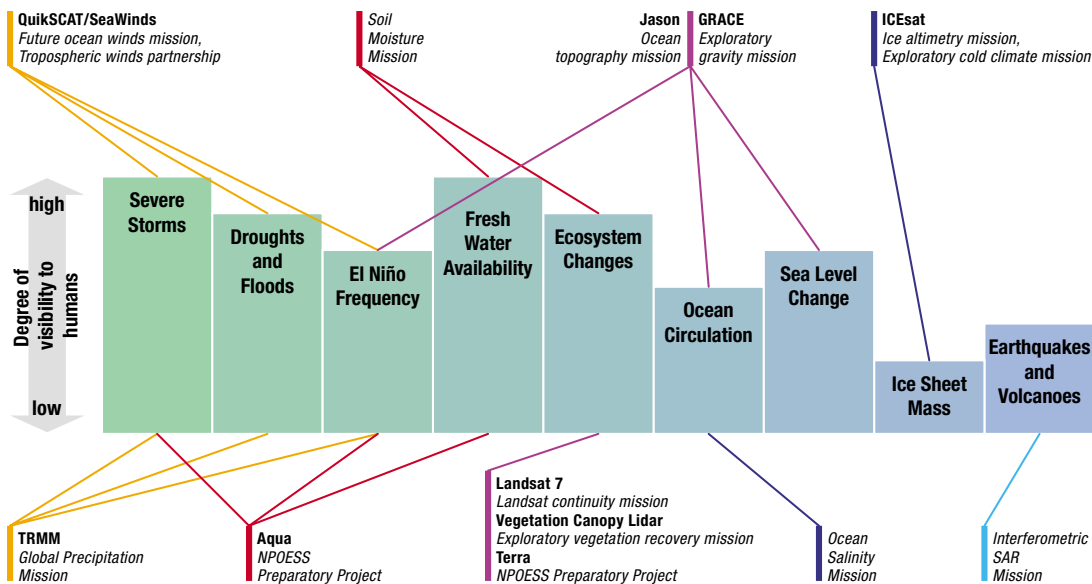


## Observing Missions/Next Decade Mission Concepts to Address Earth Science Questions

### Earth System Forcing



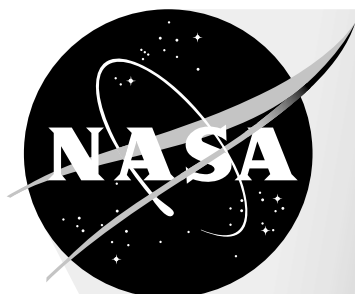
### Earth System Response



*Italics indicates 2003-2010 candidate mission concepts. The actual missions to be pursued and the order in which they occur will be determined by applying the science and implementation criteria shown on the preceding page. Rather than establish a 10-year queue of missions, the Enterprise will enable advances in science and technology to influence mission planning more frequently. All future missions will be solicited through open announcements and selected based on established scientific and technical evaluation processes.*

# Earth Science Center Roles and Missions

NASA's research and spaceflight Centers are the engines of progress in Earth System Science. Scientists at these Centers conduct leading-edge research as well as enable research performed at universities. They assure the scientific quality of our satellite and aircraft projects. The Centers are program and project managers and implementers, developing advanced technologies and integrating them into research missions. The Center Directors together with the Headquarters Office of Earth Science leadership comprise the senior management team planning and directing the Earth Science Enterprise. Each Center's role reflects its unique expertise.

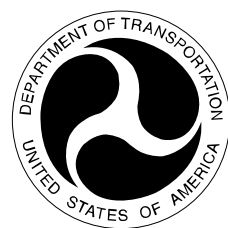
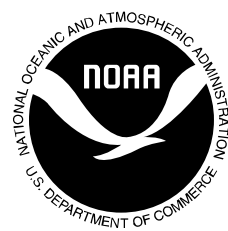


COE/Agency Mission: Lead Center Assignments:  Science Role:  Mission Role:	<b>Goddard Space Flight Center (GSFC—Greenbelt, MD)</b> Earth Science EOS/Earth Explorers/ES Technology Program/Weather Satellites/ Education Comprehensive Earth Science and Interdisciplinary Earth System Science Technology Development (Instruments, Spacecraft, Ground Systems)/Airborne Science Operations (Wallops)
Agency Mission: Lead Center Assignment:  Science Contribution: Mission Contribution:	<b>Jet Propulsion Laboratory (JPL—Pasadena, CA)</b> Instrument Technology Focused Physical Oceanography and Solid Earth Science/ New Millennium Program Oceanography, Solid Earth Sciences, and Atmospheric Chemistry Instrument Development
Agency Mission: Lead Center Assignment: Science Contribution:	<b>Stennis Space Center (SSC—Stennis, MS)</b> Remote Sensing Applications Remote Sensing Applications Coastal Research
Agency Mission: Lead Center Assignment: Science Role:  Mission Contribution:	<b>Langley Research Center (LaRC—Hampton, VA)</b> Atmospheric Science Focused Atmospheric Science Missions Atmospheric Aerosols and Chemistry, Earth Radiation Budget Atmospheric Science-related Technologies, Engineering and Instrument Development
COE: Mission Role:	<b>Dryden Flight Research Center (DFRC—CA)</b> Atmospheric Flight Operations Airborne Science Operations
COE/Agency Mission: Lead Center Assignment: Science Contribution: Mission Contribution:	<b>Ames Research Center (ARC—Moffet Field, CA)</b> Information Technology/Astrobiology/HPCC Information Technology/Astrobiology/HPCC Terrestrial Ecology and Atmospheric Assessments Information Systems and Technology/Airborne Instrument Development
Science Contribution:  Mission Contribution:	<b>Marshall Space Flight Center (MSFC—Huntsville, AL)</b> Hydrometeorology/Hydroclimatology, includes Passive Microwave Data Analysis and Atmospheric Electricity/Land Processes/Regional Applications Instrument Development

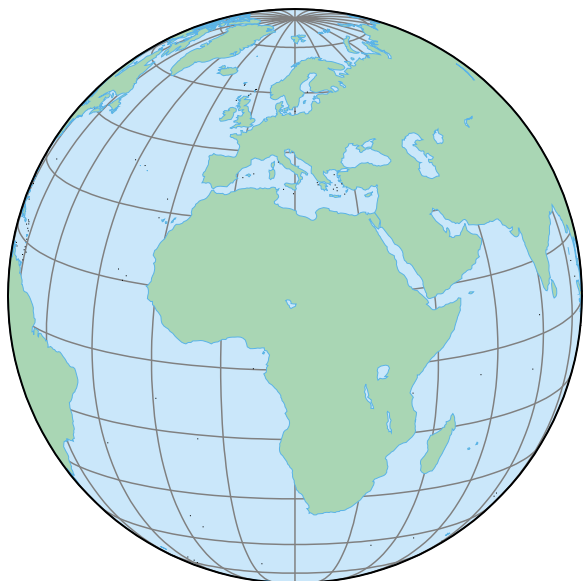
# Interagency Partnerships

NASA is not alone in the conduct of Earth Science; indeed, the Earth Science Enterprise depends on an extensive web of partnerships to fulfill its mission. These partnerships are the means by which new scientific understanding and observing capabilities become new and better services for the Nation.

- NASA builds operational weather satellites for the **National Oceanic and Atmospheric Administration (NOAA)**. NOAA and NASA are collaborating on development of weather satellites and weather forecast models to improve the accuracy and duration of weather prediction. NASA, NOAA, and the **Department of Defense** are collaborating on a Bridge mission that will provide both continuity for Terra & Aqua for climate observation and research, and an operational demonstration for the NOAA/DoD converged weather satellite program. NASA, NOAA, and the **US Navy** are working together to develop and use an advanced geostationary imaging Fourier Transform Spectrometer for the next generation geostationary weather satellites.
- The **U.S. Geological Survey (USGS)** and NASA are partners in the Landsat program and the Southern California Integrated GPS Network (SCIGN). USGS archives and distributes EOS and other land remote sensing imagery through its Earth Resources Observation Satellites (EROS) Data Center.
- The **National Imagery & Mapping Agency (NIMA)** and NASA collaborated in the Shuttle Radar Topography Mission, and are engaged in the processing and distribution of that data.
- The **U.S. Department of Agriculture (USDA)** and NASA are collaborating on research in applications of remote sensing to agriculture, forestry & rangeland to improve food and fiber productivity.
- The **National Institutes of Health (NIH)** and NASA are researching the use of remote sensing to identify climate and ecosystem conditions leading to emergence of infectious diseases such as malaria and dengue fever that spread or subside in response to environmental change.
- The **National Science Foundation (NSF)** and NASA collaborate on research in the north and south polar regions and in oceanography. Along with USGS, they partner in the EarthScope program to study earthquake dynamics through such programs as the Southern California Integrated GPS Network (SCIGN). NSF and NASA also share aircraft assets for research flights.
- NASA and the **U.S. Department of Transportation (DOT)** are exploring the application of remote sensing technology in transportation planning
- NASA and 10 other agencies coordinate Earth science research activities through the **U.S. Global Change Research Program**.



## International Partnerships



Earth Science is inherently international; global scientific questions require global collaboration to obtain solutions. No single nation or region can afford comprehensive systems required to understand Earth system science. Decisionmakers around the world need an objective scientific knowledge base to plan their actions; credibility depends on international participation in the scientific process. Further, calibration/validation of space-based observations requires specialized local knowledge and in situ data from around the world. ESE has partnerships with 45 countries around the world. International contributions to EOS satellite missions total \$5 billion. Examples include:

- **Japan** is currently ESE's largest partner, conducting the Tropical Rainfall Measuring Mission, providing instruments to EOS missions and accommodating EOS instruments on its missions
- **France** and NASA are partners in the highly successful TOPEX/Poseidon mission, its successor, Jason-1, and the PICASSO-CENA mission
- **Germany** and NASA are partners in the Shuttle Radar Laboratory and the CHAMP and GRACE missions
- The **UK and the Netherlands and Finland** are contributing instruments to the EOS Aura mission
- **Canada** provided the MOPITT instrument for the Terra mission, and NASA launched Canada's Radarsat 1 mission
- **Brazil** is providing the Humidity Sounder-Brazil (HSB) instrument for the EOS Aqua mission
- **Argentina's** SAC-C satellite will be launched by NASA to form a constellation of land observing satellites with EOS Terra and Landsat 7
- **Russia** is providing a platform and launch vehicle for SAGE III instruments to measure atmospheric ozone concentration

The Committee on Earth Observation Satellites facilitates international participation in the construct of an Integrated Global Observing Strategy.

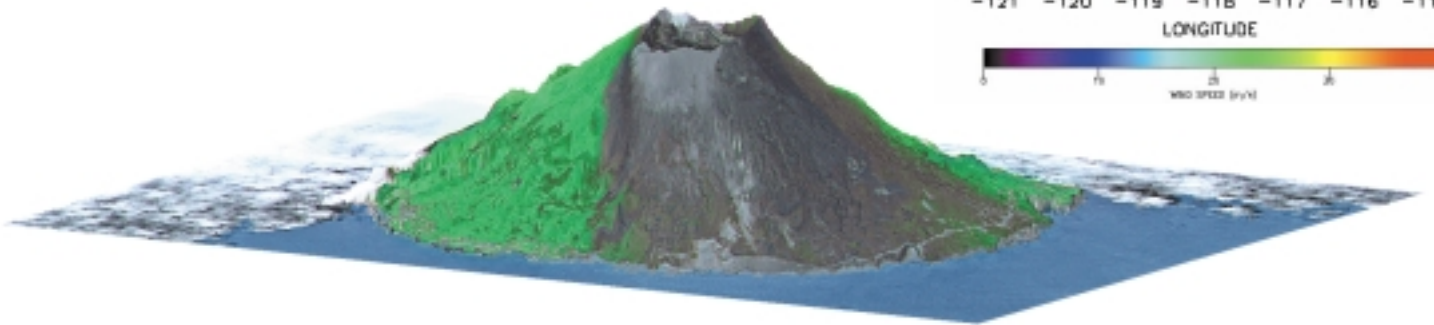
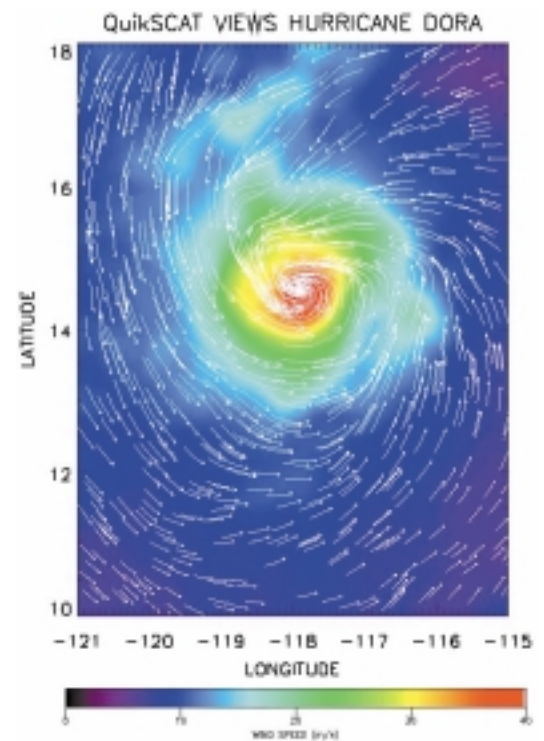
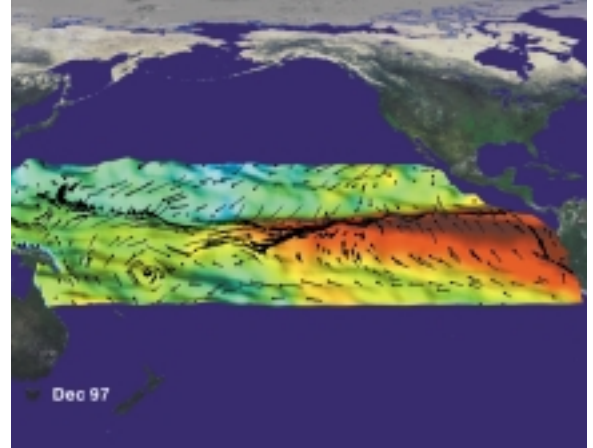
A number of international research organizations sponsor scientific programs in which ESE is an active contributor of research and observations. These include:

- World Climate Research Program
- International Geosphere/Biosphere Programme
- Intergovernmental Panel on Climate Change
- Food and Agriculture Organization
- European Center for Medium-Range Weather Forecasting
- International Oceans Commission

# A Vision of the Future: Predicting Earth System Change—Earth Science in 2025

## WHAT'S POSSIBLE IN 25 YEARS?

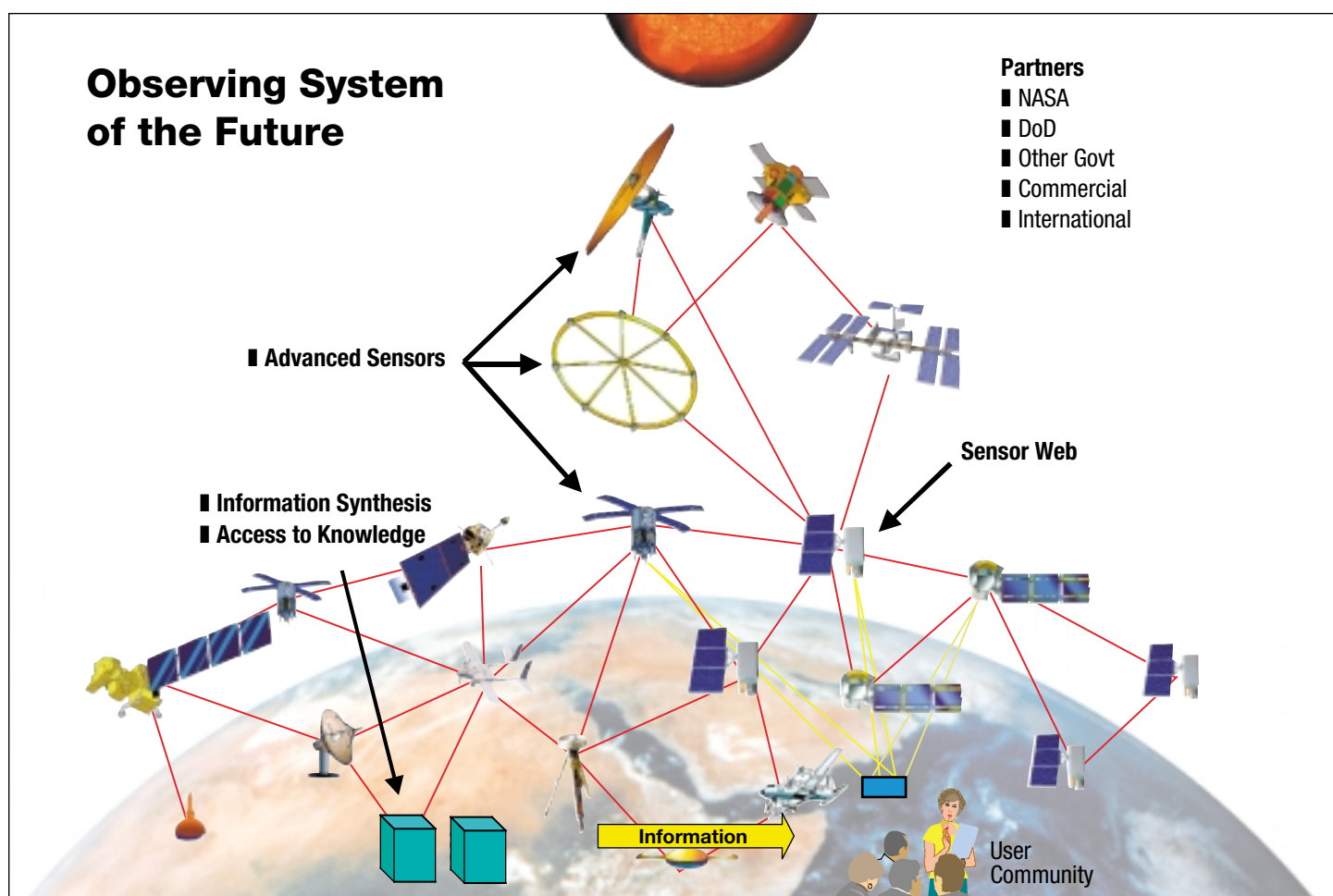
- 10-year climate forecasts
- 15- to 20-month El Niño prediction
- 12-month regional rain rate
- 60-day volcano warning
- 10- to 14-day weather forecast
- 7-day air quality notification
- 5-day hurricane track prediction to  $\pm 30$  km
- 30-minute tornado warning
- 1- to 5-year earthquake experimental forecast



## Long-Term: 2010–2020

### WHAT WILL IT TAKE TO MAKE IT HAPPEN?

Advances in observing and information technologies, research, and modeling are all required to fulfill our long-term vision for Earth system prediction. The observing system of the future will include satellites in a variety of orbits. These will include a “sensorweb” of small, smart satellites in low Earth orbit, large aperture sensors in geostationary orbits, and sentinel satellites at L1 and L2 (about 1.5 kilometers from Earth) to provide synoptic day/night views of the entire globe from pole to pole. On-board data processing and high speed computing and communications will enable delivery of tailored information products from satellites direct to users at the cost of today’s international telephone calls.



As important as the technology advances to the success of this vision are the partnerships that transition new capabilities to the providers of services. NASA can provide the science and technology tools, but it will be agencies like NOAA, USGS, USDA, and FEMA, and commercial industry that make these services broadly available to the Nation.

## Long-Term: 2010–2020 continued

### WHAT TECHNOLOGY INVESTMENTS SHOULD WE BE MAKING NOW TO MAKE THIS FUTURE HAPPEN?

#### ■ Advanced sensors

Active and large aperture remote sensing instruments to make new measurements, or known measurements with higher spatial and temporal resolution.

#### ■ Networks of sensors

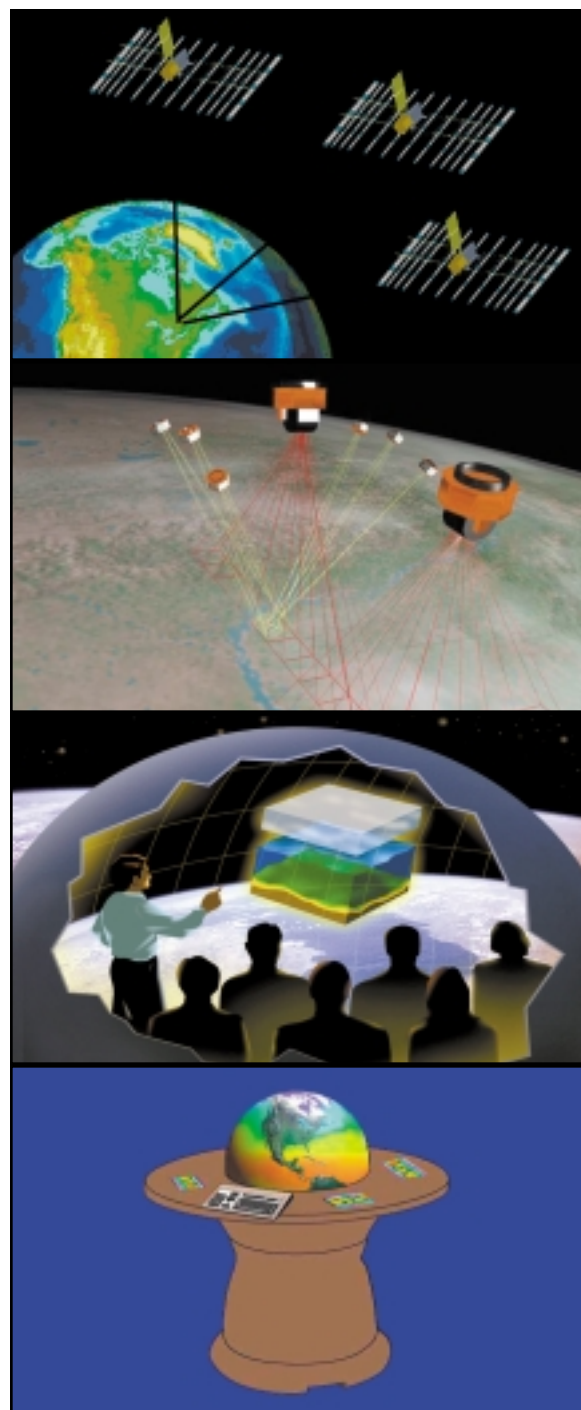
Global sensor networks capable of functioning autonomously, of being reconfigured to meet user needs, and of surviving failures of component sensors.

#### ■ Information synthesis and modeling

Computational modeling systems that improve predictive modeling to the limit of scientific understanding rather than of computing capability

#### ■ Access to knowledge

Computing and communications systems that can rapidly search, tailor, and provide useful information products in response to user queries.



The Enterprise will continue to evolve this 25-year vision through workshops and other forms of dialog with the external science, applications, and technology communities.

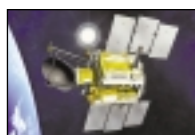
# Appendices

## Appendix 1: Earth Science Enterprise Missions

### 1999



MISSION: Landsat 7  
PURPOSE: Global land cover inventory  
LAUNCH DATE: April 1999  
LAUNCH VEHICLE: Delta



MISSION: QuikSCAT  
PURPOSE: Measure winds at the ocean surface  
LAUNCH DATE: June 1999  
LAUNCH VEHICLE: Titan



MISSION: Terra  
PURPOSE: Clouds, aerosols, terrestrial & marine biosphere, Land surface, energy budget at top of atmosphere  
LAUNCH DATE: April 1999  
LAUNCH VEHICLE: Delta

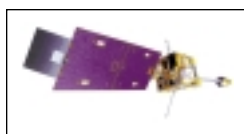


MISSION: ACRIMSAT  
PURPOSE: Solar irradiance & influence on climate  
LAUNCH DATE: December 1999  
LAUNCH VEHICLE: Taurus

### 2000



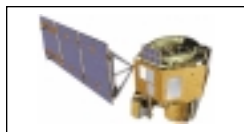
MISSION: Shuttle Radar Topography Mission  
PURPOSE: Land surface topography  
LAUNCH DATE: February 2000  
LAUNCH VEHICLE: Space Shuttle (11 day mission)



MISSION: Geostationary Operational Environmental Satellite (GOES-L)  
PURPOSE: Geostationary weather satellite for NOAA  
LAUNCH DATE: May 2000  
LAUNCH VEHICLE: Atlas



MISSION: CHAMP (GPS receiver on German satellite)  
PURPOSE: Part of GPS receiver constellation for Earth's magnetic field & experimental atmospheric sounding  
LAUNCH DATE: July 2000  
LAUNCH VEHICLE: Russian COSMOS

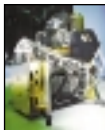


MISSION: Earth Observer-1  
PURPOSE: Land imaging technology demonstration  
LAUNCH DATE: Fall 2000  
LAUNCH VEHICLE: Delta



MISSION: NOAA-L Polar Operational Environmental Satellite (POES)  
PURPOSE: Polar-orbiting weather satellite for NOAA  
LAUNCH DATE: September 2000  
LAUNCH VEHICLE: Titan

## Appendix 1: Earth Science Enterprise Missions



MISSION: QuikTOMS  
PURPOSE: Total column ozone mapping  
LAUNCH DATE: Fall 2000  
LAUNCH VEHICLE: Taurus

### 2001



MISSION: SAGE III on Russia's Meteor 3M  
PURPOSE: Stratospheric aerosols & gases  
LAUNCH VEHICLE: Russian/Ukraine Zenit-2



MISSION: Jason  
PURPOSE: Ocean surface topography  
LAUNCH VEHICLE: Delta



MISSION: Aqua  
PURPOSE: Atmospheric temperature & moisture, terrestrial & marine biosphere, sea surface temperature, energy budget at top of atmosphere  
LAUNCH VEHICLE: Delta



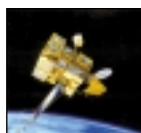
MISSION: Vegetation Canopy Lidar (VCL)  
PURPOSE: 3-D forest canopy measurement  
LAUNCH VEHICLE: TBD



MISSION: GRACE  
PURPOSE: Precise map of Earth's geoid  
LAUNCH VEHICLE: Russian ROCKOT



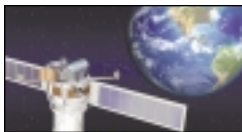
MISSION: ICESat  
PURPOSE: Ice sheet topography  
LAUNCH VEHICLE: Delta



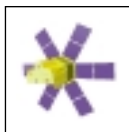
MISSION: SeaWinds on Japan's ADEOS 2  
PURPOSE: Ocean surface topography  
LAUNCH VEHICLE: Japan's H-IIA

## Appendix 1: Earth Science Enterprise Missions

### 2002-2003



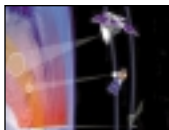
MISSION: Triana  
PURPOSE: Earth remote sensing from L1  
LAUNCH VEHICLE: Space Shuttle



MISSION: SORCE  
PURPOSE: Total and UV solar irradiance  
LAUNCH VEHICLE: Pegasus



MISSION: PICASSO-CENA  
PURPOSE: Aerosol vertical profiles  
LAUNCH VEHICLE: Delta (w/Cloudsat)



MISSION: Cloudsat  
PURPOSE: Cloud vertical profiles  
LAUNCH VEHICLE: Delta (w/PICASSO-CENA)



MISSION: Aura  
PURPOSE: Stratospheric & tropospheric chemistry  
LAUNCH VEHICLE: Delta



MISSION: Stratospheric Aerosol & Gas Experiment (SAGE III)  
PURPOSE: Stratospheric aerosols & gases  
LAUNCH VEHICLE: Deployed via Space Shuttle to the International Space Station

### AIRBORNE SCIENCE ASSETS



CRAFT: DC-8  
PURPOSE: Heavy lift laboratory for remote sensing and upper troposphere *in situ* observations.



CRAFT: P3-B  
PURPOSE: Rugged, heavy lift laboratory for low altitude remote sensing.



CRAFT: ER-2  
PURPOSE: High altitude aircraft for stratospheric *in situ* observations and satellite simulations.

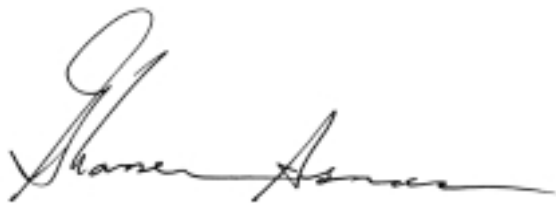


CRAFT: Uninhabited Aerial Vehicles (UAV's)  
PURPOSE: Long duration autonomous vehicles for *in situ* and remote sensing.

## Appendix 2: Earth Science Enterprise Statement on Data Management

This Statement elaborates on Executive Branch and other legal guidance for data management by the Earth Science Enterprise. The following 11 statements summarize the main principles drawn from that guidance. The full Statement is available on the ESE Home Page at: <http://www.earth.nasa.gov/visions/data-policy.html>

1. NASA shall plan and follow data acquisition policies that ensure the collection of long-term data sets that will satisfy the research requirements of the Earth Science Enterprise.
2. NASA is committed to the full and open sharing of Earth Science data obtained from U.S. Government-funded and -owned systems with all users as soon as such data become available. All Earth System Enterprise missions, projects, grant proposals shall include data management plans to facilitate implementation of this principle.
3. For data from government-owned or -funded systems, NASA will enforce a principle of non-discriminatory access so that all users within the same data use category will be treated equally. Preferential treatment for U.S. government users and affiliates will be allowed only where expressly permitted by law.
4. NASA shall make data from the Earth Science Enterprise available at a reasonable price to facilitate access and encourage use. Data from NASA and its U.S. government partners shall be priced at the cost of dissemination or, in cases where such pricing would unduly inhibit use, below that cost. For data from industry and foreign partners in the Earth Science Enterprise, pricing and access policies shall be established by negotiation between NASA and the relevant Earth Science Enterprise provider and system operator. NASA will seek to ensure consistency in negotiate pricing and access policies in a manner consistent with the principles in this Statement.
5. All data required for long-term global change research shall be archived. Data archives shall include easily accessible information about the data holdings, including quality assessments, supporting relevant information, and guidance for locating and obtaining data.
6. Where cost-effective, NASA shall make purchases of commercial data to meet the scientific objectives of the Earth Science Enterprise. Data purchase arrangements should, at a minimum, permit appropriate use, distribution, and duplication of the data for Earth Science Enterprise purposes by all researchers affiliated with the Earth Science Enterprise. NASA may purchase data on behalf of, and through, other federal agencies for research and investigation purposes.
7. For each cooperative activity with industry, domestic or foreign, NASA shall seek agreement on all major data management and distribution issues during the project definition phase. The respective contributions of the parties to the activity shall be considered in allocating rights and control over results from the activity. NASA shall seek to ensure meaningful use of the data for Earth Science Enterprise purposes by all researchers affiliated with the Enterprise.
8. NASA shall engage in on-going cooperation with other federal agencies, particularly those involved with space-based activities or Earth Science research, to increase the effectiveness and reduce the cost of the Earth Science Enterprise. This interagency cooperation shall include: sharing of data from satellites and other sources, mutual validation and calibration of data, and consolidation of duplicative capabilities and functions.
9. NASA shall, in compliance with applicable federal law and policy, negotiate and implement arrangements with its international partners, with an emphasis on meeting the Nation's own data acquisition, distribution, and archival needs.
10. NASA may allow for exceptions to the guidance contained in this Statement on a case-by-case basis where permitted by law and in furtherance of the public interest.
11. NASA shall review and, if warranted, update this Statement as part of the biennial review of the Earth System Enterprise.



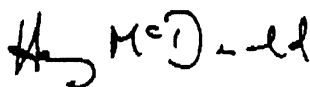
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**Henry McDonald**

Director  
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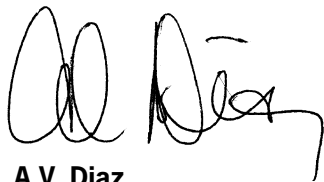
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National Aeronautics and  
Space Administration

Earth Science Enterprise

Code Y

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